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PYROTECHNICS AND EXPLOSIVES
APPLICATIONS SECTION

ANNIVERSARY FORT WORTH, TEXAS

1983

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TABLE OF CONTENTS

AN ADDRESS BY THE
HONORABLE J. R. SCULLEY
ASSISTANT SECRETARY OF THE ARMY
(RESEARCH, DEVELOPMENT AND ACQUISITION)
BEFORE THE
1983 ANNUAL MEETING OF THE
PYROTECHNICS AND EXPLOSIVES
APPLICATIONS SECTION
AMMUNITION TECHNOLOGY DIVISION
AMERICAN DEFENSE PREPAREDNESS ASSOCIATION
AT FORT WORTH, TEXAS
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DEPARTMENT OF DEFENSE

3593

GOOD AFTERNOON.

ACKNOWLEDGE INTRODUCTION.

ACKNOWLEDGE SECTION CHAIRMAN, OTHER DISTINGUISHED ATTENDEES.

AS ALWAYS, I WAS HONORED TO BE INVITED TO ATTEND THIS SESSION WITH YOU AND PARTICULARLY PLEASED THAT I COULD ACCEPT YOUR GRACIOUS INVITATION TO SPEAK WITH YOU AS YOU MEET HERE IN FURTHERANCE OF THE DEFENSE OF THE NATION.

I AM VERY IMPRESSED WITH THE RANGE AND DEPTH OF YOUR CONSIDERATIONS AT THIS MEETING REPRESENTING THE 25TH SILVER ANNIVERSARY OF YOUR EFFORTS. IT IS CLEAR FROM READING THE TITLES IN YOUR BROCHURES, IF FROM NOTHING

ELSE, THAT WE HAVE MADE REMARKABLE PROGRESS IN THE LAST 25 YEARS. IT IS ALSO CLEAR FROM THAT SAME LIST OF TOPICS THAT THE PROGRESS IS CONTINUING AT AN INCREASING RATE.

BUT CONGRATULATIONS ON WHAT YOU HAVE DONE AND WHAT YOU ARE DOING IS ONLY ONE OF MY PURPOSES TODAY. MY OTHER PURPOSE IS TO URGE YOU ON TO EVEN BETTER AND BIGGER THINGS. I THROW DOWN THE GAUNTLET, I GIVE YOU THE CHALLENGE.

THE REASON FOR THE CHALLENGE IS CLEAR. DESPITE OUR FONDEST HOPES, OUR BEST INTENTIONS, WE LIVE IN A DANGEROUS WORLD. EVENTS DURING THE PAST YEAR CLEARLY ILLUSTRATE THE DANGERS WE FACE. THE WAR IN THE FALKLANDS, THE WAR BETWEEN IRAN AND IRAQ, THE CONTINUING VIOLENCE OVER MUCH OF THE CONTINENT OF AFRICA. WAR

AND RUMOR OF WAR CLOSE TO HOME IN CENTRAL AMERICA. OUR PEOPLE DYING IN BEIRUT AND THE SINGLE MAD, LASHING OUT OF THE SOVIET UNION AGAINST AN UNARMED PASSENGER PLANE COSTING THE LIVES OF 269 PEOPLE. ALL OF THESE THINGS TELL US THAT NO MATTER WHAT WE WANT, WE MUST BE PREPARED TO DEAL WITH THE HORRIBLE THOUGHTS AND ACTIONS OF WAR.

A LOOK AT ALL THE MAJOR CHOKE POINTS AND POTENTIAL FLASH POINTS AROUND THE WORLD SHOWS THE UNCERTAINTY AND VARIETY OF SCENARIOS IN WHICH THE ARMY MUST BE PREPARED TO DEFEND OUR NATIONAL INTERESTS.

IT IS THIS SPECTRUM OF CONFLICTS THAT DEFINES THE ARMY MISSION AND, THEREFORE, OUR WEAPONS SYSTEMS DESIGN AND THE MIX OF HARDWARE

NECESSARY TO FULFILL OUR OBLIGATIONS. THE VARIED TERRAINS, ENVIRONMENTS, LOGISTICS, AND THREATS DETERMINE THE OPERATING NEEDS OF THE ARMY. THESE FACTORS, IN TURN, IMPACT THE STRUCTURE OF OUR FORCES FROM THE HEAVY TO LIGHT DIVISIONS AND THE NEW HIGH TECHNOLOGY DIVISION NOW UNDER DEVELOPMENT.

FOR EXAMPLE, OUR LIGHTEST DIVISION FORCE, THE AIRBORNE DIVISION, IS KEYED TO STRATEGIC PROJECTION WITH FORCEABLE ENTRY CAPABILITIES. AT THE OTHER EXTREME, THE MECHANIZED OR ARMOR DIVISIONS ARE DESIGNED TO DEFEAT ARMOR INTENSIVE ENEMY FORCES IN BATTLES FOUGHT OVER A WIDE RANGE OF AREAS. THESE DIVISIONS REQUIRE CONSIDERABLE SUPPORT TO SUSTAIN OPERATIONS AND ARE STRATEGICALLY THE MOST DIFFICULT TO EMPLOY.

THE DIFFERENT ENVIRONMENTAL CONDITIONS WE WOULD EXPECT TO ENCOUNTER IN EUROPE VS. PARTS OF THE MIDDLE EAST, ALSO IMPACT HARDWARE DESIGN. IN EUROPE, WE MUST OPERATE IN RELATIVELY COLD TEMPERATURES -- WITH FOG, SNOW, OR DARKNESS 70 PER CENT OF THE TIME -- ON HIGHWAYS, MUDDY OR SNOWY FIELDS, AND URBAN STREETS WHERE WE CAN EXPECT HEAVY CONCENTRATION OF ENEMY FORCES.

IN MANY PARTS OF THE MIDDLE EAST WE MUST BE PREPARED TO ENCOUNTER HIGH TEMPERATURES, BLOWING SAND, AND A WIDELY DISPERSED ENEMY.

IN OTHER PARTS OF THE WORLD WE WOULD FACE JUNGLE OR TROPICAL ENVIRONMENTS. ALL OF THESE FACTORS IMPACT OUR WEAPONS SYSTEM DESIGN AND THE MIX OF HARDWARE REQUIRED TO SUCCESSFULLY EXECUTE OUR MISSION.

IN CONSIDERATION OF ALL OF THESE FACTORS I HAVE OUTLINED, OUR MANAGEMENT STRATEGY IS TO COORDINATE THE ARMY'S RESEARCH, DEVELOPMENT AND ACQUISITION EFFORTS TO DEPLOY AN INTEGRATED FAMILY OF HIGHLY MOBILE TECHNOLOGICALLY LEVERAGED WEAPONS WHICH INSURE MAXIMUM SURVIVABILITY OF OUR SOLDIERS ACROSS THE SPECTRUM OF CONFLICTS THEY MAY FACE.

TO DO THIS WE ARE EMPHASIZING MOBILITY, FLEXIBLE MISSION USES, AND REDUCED LOGISTICS SUPPORT REQUIREMENTS. THE ARMY'S MODERNIZATION PROGRAM WAS DESIGNED TO MEET THESE OBJECTIVES AND WITH YOUR SUPPORT THIS NEW GENERATION OF WEAPONS SYSTEM IS NOW IN PRODUCTION.

AT THE SAME TIME, IN A TECHNOLOGICALLY VOLATILE ENVIRONMENT WE CANNOT IGNORE OUR

FUTURE NEEDS. IT IS HERE THAT THE CHALLENGE TO YOU IS MOST SIGNIFICANT.

TO ACHIEVE A BALANCE BETWEEN OUR MODERNIZATION EFFORTS AND THE NEXT GENERATION THREAT, WE ARE FOCUSING OUR RESEARCH AND DEVELOPMENT EFFORTS ON KEY LEVERAGE TECHNOLOGIES. THIS STRATEGY WILL MINIMIZE THE COST OF DEVELOPING FUTURE SYSTEMS WHILE TAKING FULL ADVANTAGE OF YOUR SCIENTIFIC STRENGTHS. WE HAVE IDENTIFIED FIVE FUNCTIONAL THRUSTS WHICH WILL FORM THE NUCLEUS OF FUTURE SYSTEMS. THESE INCLUDE VISTA -- VERY INTELLIGENCE SURVEILLANCE AND TARGET ACQUISITION DEVICES; DISTRIBUTED COMMAND CONTROL COMMUNICATIONS AND INTELLIGENCE; SELF CONTAINED MUNITIONS; THE SOLDIER MACHINE INTERFACE; AND BIOTECHNOLOGY.

WE PLAN TO CONTROL THE IMPLEMENTATION OF NEW TECHNOLOGIES WITH CONFIGURATION MANAGEMENT DECISIONS AT THE HEADQUARTERS LEVEL AND WILL USE PREPLANNED PRODUCT IMPROVEMENT WHEREVER POSSIBLE. THERE IS ANOTHER ASPECT OF MY CHALLENGE TO YOU. GIVE US NEW THINGS BUT GIVE US WAYS THAT WE CAN INCORPORATE THESE NEW THINGS IN THE SYSTEMS WE NOW HAVE. THIS WILL ALLOW US TO EXTEND THE USEFUL LIFE OF EXISTING SYSTEMS, REDUCE THE LABORATORY TO DEPLOYMENT TIME AND MINIMIZE THE PROBABILITY OF TECHNOLOGICAL SURPRISE.

WHEN I SPEAK TO YOU OF NEW SYSTEMS OF NEW THINGS BY THEMSELVES OR INCORPORATED IN EXISTING SYSTEMS, I SPEAK NOT ONLY OF THE TECHNOLOGICAL ADVANCES ACHIEVED IN THE LABORATORY TO GIVE US NEW CAPABILITIES, BUT

ALSO OF THE MANAGERIAL AND ECONOMIC ADVANCES WHICH WE NEED TO GET THESE GOOD THINGS, THESE EFFECTIVE WEAPONS AND COMPONENTS INTO THE HANDS OF OUR TROOPS IN THE SHORTEST TIME AND AT THE MOST REASONABLE PRICE.

WE NEED TO BE LOOKING AT EXPLOSIVES WHICH ARE BY WEIGHT AND VOLUME NOT SIMPLY TWICE AS GOOD AS THE ONES WE HAVE NOW, BUT TWO OR THREE HUNDRED TIMES AS EFFECTIVE. WE NEED TO THINK OF OBSCURANCE IN TERMS OF A VERY WIDE SPECTRUM, ALMOST A COMPLETE SPECTRUM WITH SENSORS IN EVERY AREA THAT CAN SEE, HEAR, AND FEEL.

AS LONG AS MUCH OF THE WORLD LOOKS TO US FOR LEADERSHIP AND INDEED PROTECTION, AS LONG AS THE WORLD IS INHABITED BY THOSE WHO SEEK TO IMPOSE THEIR WILL ON OTHERS, AS LONG AS

THOSE WHO WOULD OPPOSE US OUT NUMBER US AND PRODUCE WITHOUT REGARD TO THEIR CITIZENRY MASSIVE AMOUNTS OF HIGH QUALITY MILITARY GOODS. WE MUST ALWAYS BE LOOKING FORWARD, FAR FORWARD. IT IS NOT ENOUGH THAT OUR WARHEADS ARE AS GOOD AS THE ENEMY'S BECAUSE HE HAS MORE OF THEM. ONE FOR ONE COMPARISONS ARE GENERALLY MEANINGLESS IN OUR BUSINESS. WE MUST ALWAYS STRIVE FOR THE BEST WE CAN GET. THAT BEST ALSO MEANS THAT WE CAN GET IT WITHOUT BANKRUPTING THE UNITED STATES AND DRIVING THE POOR TAXPAYER TO DESPAIR.

THERE HAVE BEEN MANY ALLEGATIONS THAT OUR EFFORTS TO SPEED THE IMPLEMENTATION OF HIGH TECHNOLOGY IN WEAPON SYSTEMS AND COST MANAGEMENT CONTROL ARE MUTUALLY EXCLUSIVE OBJECTIVES. IN REALITY, THEY ARE COMPLEMENTARY AND IN MANY CASES, DEPENDENT ON EACH OTHER.

IN MY OPINION, SUPERIORITY IN WEAPONS, MACHINERY OR ANY OTHER AREA IS NOT A 100 YARD DASH OR EVEN A FIVE MILE RUN BUT RATHER AN ENDLESS MARATHON IN WHICH WE MUST BE CONTINUOUSLY INNOVATIVE, PROGRESSIVE, AND PERSISTENT TO STAY AHEAD. THE CORNER STONE OF THIS PHILOSOPHY IS DISCIPLINE -- PERSONAL, ORGANIZATIONAL, AND MANAGERIAL.

I VERY PURPOSEFULLY HAVE NOT CHALLENGED YOU TO COME FORWARD WITH A MIRACULOUS NEW WARHEAD FOR HUNDRED FIVE MILLIMETER PROJECTILES NOR FOR A NEW WAY OF SCREENING THE ADVANCE OF OUR ARMORED COLUMNS NOR FOR NEW APPROACHES TO CUTTING AND SEPARATION NOR INDEED FOR ANY SPECIFIC PRODUCTION METHODOLOGY. THOSE THINGS MUST COME FROM PERHAPS AN EVEN MORE IMPORTANT CHALLENGE, THE CHALLENGE THAT YOU GIVE YOURSELF.

YOU ASSEMBLED HERE ARE BOTH GOVERNMENT AND INDUSTRY. COLLECTIVELY AND INDIVIDUALLY YOU AND I NEED TO SET OUR GOALS HIGHER. THERE IS NO SATISFACTION MORE PLEASANT THAN THE ACHIEVEMENT OF A HARD WON GOAL MADE EVEN MORE SIGNIFICANT BY THE VERY REAL CONTRIBUTION YOU KNOW IT MAKES TO THE DEFENSE OF THE NATION AND THE FREEDOM OF THE WORLD.

THANK YOU FOR GIVING ME THIS TIME TO SPEAK TO YOU AND CONGRATULATION ON YOUR SILVER ANNIVERSARY AND ALL THE FINE WORK YOU HAVE DONE, ARE DOING, AND WILL DO.

THANK YOU VERY MUCH.

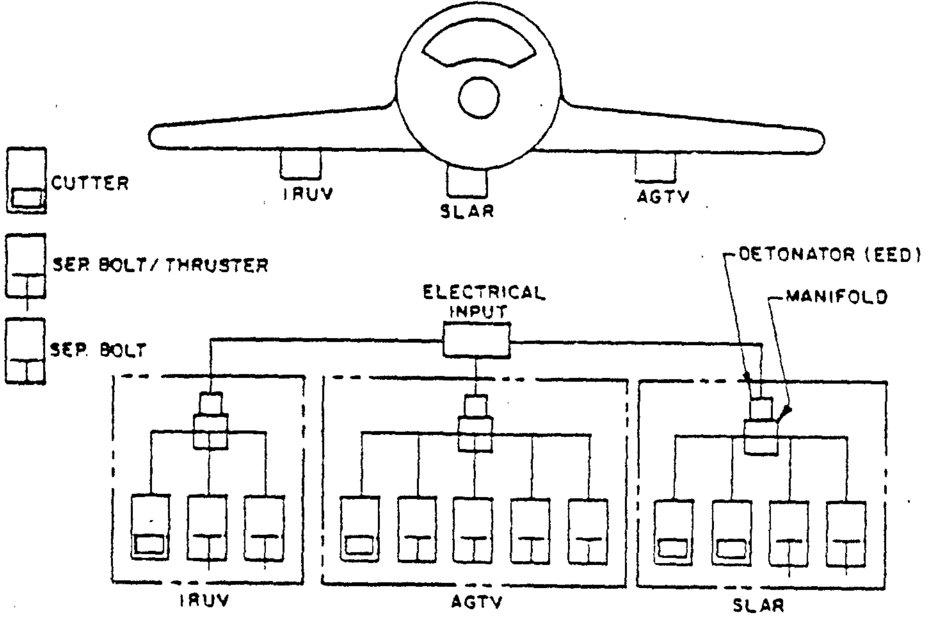
Design and Development
of a
Pod Separation System

K.L. Von Der Ahe
Space Ordnance Systems
Canyon Country, California

The Coast Guard HU/25A Search and Rescue Aircraft (AIREYE) has three Avionics Pods mounted to it. In the event of an emergency, these pods are required to be released simultaneously. A system was designed which pyrotechnically severed aircraft electrical connections and combined load carrying attachments with thrust for a specified energy and time profile. Specifically, a system including the following components was designed and developed:

- RF/EMI Shielded Detonator
- SMDC Initiated Electrical Cable and Waveguide Cutter
- SMDC Initiated Separation Bolt (3/8")
- SMDC Initiated Separation Bolt (1/2") /Integral Thruster

This paper discusses some of the problems encountered and their solutions along with development tests and results.



AIREYE POD SEPARATION SYSTEM

INTRODUCTION

When designing pyrotechnics to perform a designated task, a systematic and purposeful approach can insure success with a minimum of development testing. The goal is [illegible] asc[illegible] and eliminate any pro[illegible]sa. before the hardware is [illegible]tured. The preliminary anal[illegible]ns with a definition of [illegible] or task to be performed. [illegible]g from this, are the functional parameters by which the task can be accomplished. Finally, there are the requirements of overall envelope , and the subsequent sizes/weights of the individual subcomponents. Beyond this, specifications of center of gravity, moments of inertia, loads and other static and dynamic features may be called out. As a general rule, all of these requirements are supplied by the procuring activity. Given this information the engineer can begin the job of designing the system.

DESCRIPTION

OF POD SEPARATION SYSTEM

Three pods must be severed completely and thrust away from the aircraft. This must be accomplished by severing or releasing the load carrying attachments and severing umbilical connections. Each pod is unique in it's weight, profile and center of gravity. The AGTV (air-to-ground television) pod located under the left wing, is the only pod not requiring thrust after separation, due to its weight.

The ordnance subcomponents required for release of the AGTV pod are:

- Separation Bolt

  Thread: 3/8-24UNF-3A
  Proof load: 5,000 ± 100 lbs.
  Limit load: 7,500 ± 100 lbs.
  Ult. load: 11,600 ± 100 lbs.

- Cable Cutter

  Capable of severing completely three (3) electrical wire bundles, .65 inch diameter each.

The IRUV (infrared / ultraviolet) pod, located under the right wing, and the SLAR (Sea, Land and Air Radar) pod, located under the fuselage, both require thrusting from the aircraft after severance. The thrust parameters include: initial force, final force, stroke and total energy. The ordnance components for release and thrusting of the IRUV and SLAR pods are:

IRUV

- Separation Bolt / Thruster

  Thread: 1/2-20UNF-3A
  Proof load: 5,000 ± 100 lbs.
  Limit load: 7,500 ± 100 lbs.
  Ult. load: 11,600 ± 100 lbs.

- Cable Cutter

  Capable of severing, completely, three (3), .65 inch diameter, electrical wire bundles.

SLAR

- Separation Bolt / Thruster

  Thread: 1/2-20UNF-3A
  Proof load: 8,000 ± 100 lbs.
  Limit load: 12,000 ± 200 lbs.
  Ult. load: 15,000 ± 200 lbs.

- Cable Cutter

  Capable of severing, completely, either--(1) Three, .65-inch diameter, electrical wire bundles or--(2) One, .65-inch diameter, electrical wire bundle and one flexible waveguide.

The separation bolts for the IRUV and SLAR pods incorporated an integral thruster in the form of a secondary piston which would follow through, after bolt separation. Each separation bolt used in the IRUV and SLAR pods is designed to meet a specified individual energy profile. Hence, there are four (4) different bolts (two per pod).

Because each pod must be released upon receipt of one electrical signal, further pyrotechnics are used to accept this signal, convert it to a usable energy and transfer the energy to each separation device. The pyrotechnic sequence of events begins when an EMI/RF shielded initiator / detonator which receives the input signal, and detonates, propagating explosive energy, thru a manifold, to shielded mild detonating cord (SMDC) transfer lines.

The explosive transfer is fully contained within the manifold. The SMDC's each, in turn, transfer explosive energy to one of the functional devices in which it is terminated. Each device accepts explosive energy from the connected SMDC line and initiates its own sequence of events, resulting in performance of the pod separation task. Using a minimum of input power all of the devices function quickly and simultaneously.

COMPONENTS

In addition to the functional parameters the following were major items of consideration in the design of the individual components:

- Use of readily available materials to reduce cost and time to obtain.
- Minimum of detail parts for ease of assembly and reliability of operation.
- Maximum safety factor without compromising performance.
- Use of standard fasteners where possible to save time developing new items.
- Detail parts to be interchangeable with other components to decrease item attrition during manufacturing.
- Similarity of components where ever possible to shorten development time.

The most challenging component to design was the separation bolt / integral thruster. The very concept integrated two separate devices into one. Tha primary obstacle to overcome was obtaining a rapid decrease in the force required to sever the bolt, to the relatively less force needed for the thruster. This was accomplished by nesting a secondary piston inside of the primary piston. The pressure area of the primary piston when acted upon by the gas pressure from the pressure cartridge produced sufficient force to shear a section and sever the bolt. The primary piston bottoms after a minimum stroke leaving the secondary piston free to continue on. However, the pressure area is smaller, so it will continue with much less force acting upon it. Also, the free volume is increasing less rapidly, so the force on the thruster will be more uniform over the stroke. The dual piston configuration is as depicted in Figure 1.

This concept was maintained for the four bolts used in the IRUV and SLAR pods. But, since the energy profiles were different, each bolt had to be individually tailored. All four bolts were identical in design with the exception of:

- Secondary piston pressure area
- Pressure cartridge output
- Initial free volume

These items were adjusted analytically during the design. The only change required during development was to the cartridge output. Minor adjustments were made to compensate for powder efficiency losses. The load carrying capabilities for the SLAR bolts were larger than those of the IRUV and this was also taken into consideration during the analysis. The performance requirements of the thrusters are as shown in Table I.

There was a 2.75 inch stroke requirement for each thruster. The initial force had to be within the first 2% of the stroke. Hence, the primary piston stroke was limited to 0.055 inches maximum. This was more than sufficient to sever the bolt.

The bolt for the AGTV pod, while it did not require thrusting capabilities, did require an extremely low profile due to a lack of available space in the pylon. The design is similar to the IRUV and SLAR bolts in concept, but is lacking a secondary piston. The AGTV bolt is as shown in Figure 2.

When the preliminary analyses of the functional requirements were completed the method of receiving energy from the SMDC input line was addressed. A deformable firing pin, of an existing design, was chosen to ignite a percussion primer in a pressure cartridge. The design of the pressure cartridge, identical for all four thrusting bolts, is similar to the AGTV bolt. Quan-

SEPARATION BOLT / THRUSTER

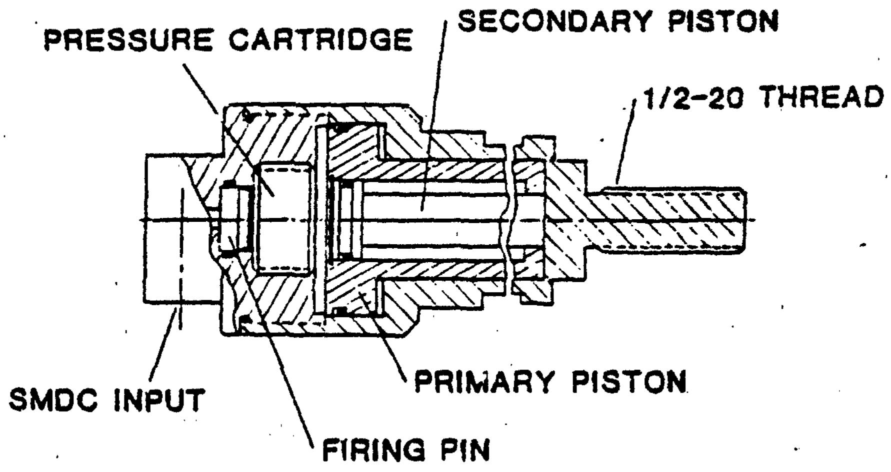


FIGURE 1

SLAR

Separation Bolt/Integral Thruster

THRUST PARAMATERS	FORWARD	AFT
Initial Force (lbs.)	3220	870
Final Force (lbs.)	1610	435
Total Energy (ft.-lbs.)	505	136

IRUV

Separation Bolt/Integral Thruster

THRUSTER PARAMETERS	FORWARD	AFT
Initial Force (lbs.)	1480	2100
Final Force (lbs.)	444	630
Total Energy (ft.-lbs.)	192	269

TABLE 1

tity of output charge, only, is varied. The pressure cartridge has a pyrotechnic chain of percussion primer-to-booster charge-to-output charge. Each pressure cartridge is independently hermetically sealed to a leak rate no greater than $1x10^{-6}$ cubic centimeters of helium per second at a differential pressure of one atmosphere. The pressure cartridge is as shown in Figure 3.

From the detail designs parts were manufactured, and the first bolts built. No changes were made to the design as a result of the manufacturing. Using a calibrated tension test fixture, the load carrying capabilities of the bolts were tested and the results are shown in Table II.

IRUV

LOAD - LBS		RESULT
Proof:	5,000	No yield
Limit:	7,500	No yield
Ultimate:	4,600	No failure
Failure:	16,200	Average

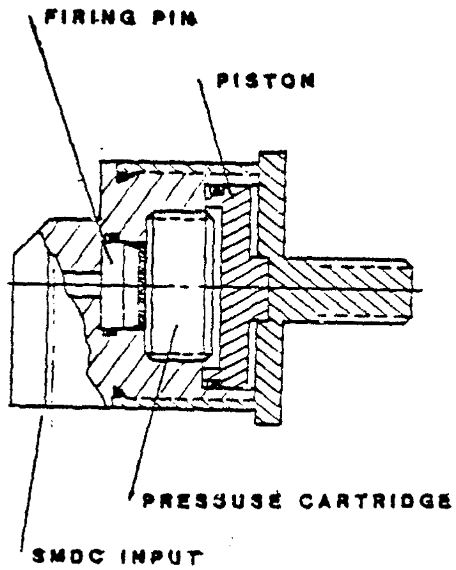
SLAR

LOAD - LBS		RESULT
Proof:	8,000	No yield
Limit:	12,000	No yield
Ultimate:	15,000	No failure
Failure:	17,000	Average

AGTV

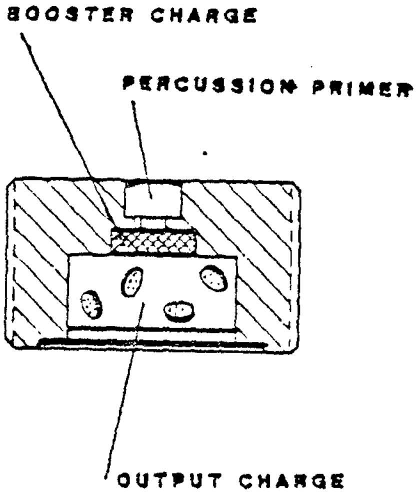
LOAD - LBS		RESULT
Proof:	5,000	No yield
Limit:	7,500	No yield
Ultimate:	11,600	No failure
Failure:	13,000	Average

TABLE II



SEPARATION BOLT

FIGURE 2



PRESSURE CARTRIDGE

FIGURE 3

All the bolts pulled to failure, sheared at the designed area with no visible metallic particles formed.

The total energy provided by the thruster portion of each bolt was tested in a fixture in which the bolt, after breaking, would thrust against a known mass having negligible friction. Using break links, the beginning and end of the stroke was measured with respect to time. The average velocity was determined by V=S/T. The total energy was calculated using $E=1/2(MV^2)$. Total energy was derived from tests performed on units conditioned at -65° and +160° F in addition to ambient temperature. Functional test data, for the IRUV and SLAR bolts, was obtained after one preliminary test of each bolt was made to size the pyrotechnic load. The calculated total energy results are in Table III.

IRUV FORWARD

Ambient - 192 Ft-lbs.
-65° F - 178 Ft-lbs.
+160° F - 190 Ft-lbs.

IRUV AFT

Ambient - 274 Ft-lbs.
-65° F - Instrumentation failure
+160° F - 274 Ft-lbs.

SLAR FORWARD

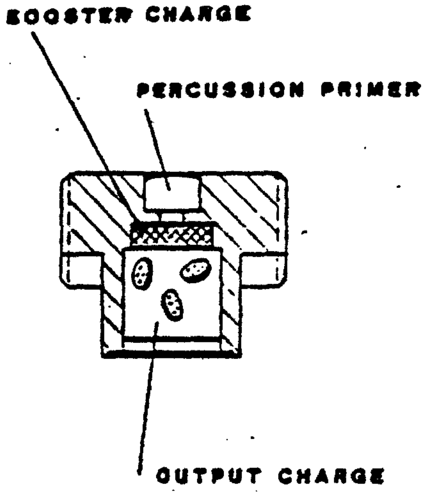
Ambient - 522 Ft-lbs.
-65° F - 518 Ft-lbs.
+160° F - 509 Ft-lbs.

SLAR AFT

Ambient - 139 Ft-lbs.
-65° F - 136 Ft-lbs.
+160°F - 141 Ft-lbs.

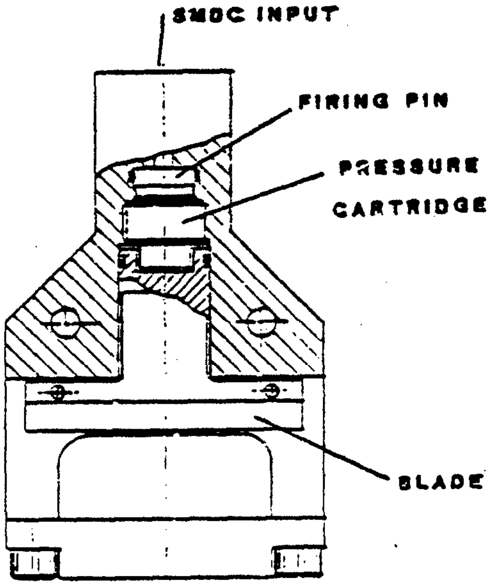
TABLE III

For simplicity and uniformity of system components, one pyrotechnic cutter was designed for use in all of the pods. The cutter was designed to cut any combination of electrical wire bundles and/or flexible waveguide as required by each pod. The pyrotechnic train used is is similar to the bolt train in design and materials. See Figure 4. This similarity is important because of function time simultaneity requirements. Function time of the cutter is measured from the detonation of the SMDC (break link) to entry of the blade into the anvil (break link). Based on the development tests performed, the average function time for the cutter is 465 microseconds. In all tests the cutter completely severed all samples, maintaining structural integrity and containing all products of combustion. One cutter was tested using a steel block to restrain blade movement. As a result of this lock-shut test the body did not yield or deform. Because the anvil is removable, an added safety feature was added to retain the blade in case of accidental initiation. The cutter configuration is shown on Figure 5.



PRESSURE CARTRIDGE

FIGURE 4



CUTTER

FIGURE 5

The SMDC lines used were purchased already manufactured in straight lengths. Bends were added as required for fitting into the pods. The SMDC lines used are identical in configuration to those used in the crew escapement system for the F-14 aircraft.

Since the maximum SMDC output lines the manifold would have to contain is five (for the AGTV), one basic manifold was designed with one input (electro-initiated detonator) and five SMDC outputs. This design was used in all three pods with quantity of outputs as follows:

<u>AGTV</u>

OUTPUTS - five
 - four bolts
 - one cutter

<u>IRUV</u>

OUTPUTS - three
 - two bolts
 - one cutter

<u>SLAR</u>

outputs - four
 - two bolts
 - two cutters

The manifold was designed with a central input port for the detonator. The detonator was located so that all output SMDC tips would be initiated simultaneously. The manifold was made from 303 stainless steel for strength and ease of machining. Tests were performed on one manifold of each output type containing one detonator and the required amount of SMDC lines. No structural failure occurred. Detonator and SMDC tips were intact and no loosening or thread failure occurred. The manifold bulged 0.015 inch maximum on the side in line with the output end of the detonator. This was expected. A post test inspection was performed verifying high-order detonation of all SMDC lines. The manifold is shown in Figure 6.

The detonator used to initiate the SMDC line was modeled after the Apollo Standard Detonator (ASD), the only difference being the electrical initiator used. Because of a relatively high EMI/RF environment, a filtered initiator similar to the one used on the Harpoon Missle program was used. This initiator has been qualified to MIL-I-23659 and incorporates a dual bridgewire for increased reliability. The functional tests performed on the detonator were done concurrent with the manifold tests.

All of the components designed for use in the Pod Separation System were subjected to non-destructive testing as required. This testing included, but was not limited to:

- o <u>Radiographic inspection</u>,

  X-ray
  N-ray

- o <u>Helium Leak Test</u>
- o <u>Proof Loading Of Load Carrying Items</u>
- o <u>Dimensional Inspection</u>
- o <u>Visual Inspection</u>

Materials selected for the components in the Pod Separation System are those used in numerous other qualified pyrotechnic devices.

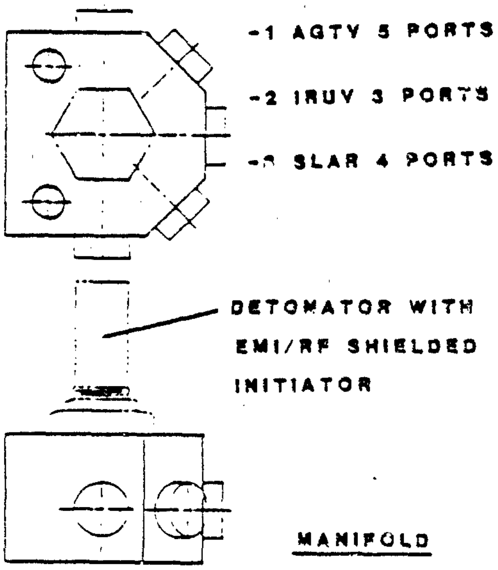


FIGURE 6

System

Verifying functional capabilities and compliance to design requirements of each component is only half of the system design task. The components must be compatable in installation and operation. Each pod in the Pod Separation System was tested with all of its components installed and functioned. These tests verified simultaneity requirements, thrusting energy and dimensional compatibility of the components with the pod.

The AGTV pod, since no thrusting is required, was simulated with a "bread board" with all of the components attached. The separation bolts were installed using 375 inch pounds. The cutter was installed with three cable samples inserted in the cutter opening. The manifold was installed with the detonator in it. The SMDC lines were installed from the manifold to the components. Each SMDC line contained the same quantity of bends as those to be used in actual pod installation. Function time of each release device was obtained using carbon break links and an oscillograph was used to record the data. The oscillograph was activated, the detonator fired and function time for each release device was recorded. Each separation bolt separated completely and cleanly. The cutter severed the electrical cable samples into two separate pieces with no residual attaching strands. The simultaneity requirement is all release devices must release within 3 milliseconds of each other. During this test each device released within an elapsed time of 1.8 milliseconds.

The IRUV and SLAR pods were tested with a full set of components. Each was mounted on a test platform in a manner that would result in the thrusters thrusting the pod upwards at a 75° angle. These tests were photographed with two high speed cameras each set at a different speed. Scales incrementally marked in feet were put by the test stand for height reference. This test verifies actual compatibility of the components and while simultaneity was not measured on a component level, any discrepancies would be shown upon review of the high speed films. The ejection profile of each pod closely followed the expected results based on calculations performed using the total thrusting energy of each separation bolt. The height was measured by reviewing the high speed films.

CONCLUSIONS

(1) Innovative design can combine multi-functions in a single unit

The physical requirement of high force to separate the bolt, and the customer requirement of a lower force for pod thrusting, suggested the need for two functional components. Innovative design put both functions together in a single envelope of bolt with integral thruster. A single cutter was designed to sever both targets interchangeably or together.

(2) Simultaneity of multiple Ordnance Operations

To achieve closest simultaneity in the pod separation functions all possible components of the same type were unitized in a single design. For example, the same manifold design was used in all three pods. Identical detonator-to-SMDC tip orientation within the manifold was maintained regardless of the number of SMDC lines connected. Used within the three pressure cartridges, are identical pyrotechnic trains. Only the quantity of output charge was varied. Simultaneity was also achieved by the SMDC lines for stimulus transfer at detonation velocity from manifold output to the functional components.

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PYROTECHNICS AND EXPLOSIVES APPLICATIONS SECTION
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GENERAL DYNAMICS
Ft. Worth, Texas

TITLE Development, Qualification, and Production of Forward and Aft Separation Bolts for the NASA Shuttle Solid Rocket Booster Separation System

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TELEPHONE

ABSTRACT

Hi-Shear Corporation recently completed design, development, and qualification of two different types of large-size, high-load, separation bolts for application on the NASA Space Shuttle vehicle. These bolts are currently in production.

The bolts serve as attachment between the two Solid Rocket Boosters (SRB) and the External Tank and separate upon command. At each SRB to External Tank interface, one Forward Separation Bolt and three Aft Separation Bolts are employed.

This program represents development of the largest known bolt of this type. Hi-Shear had previously developed a bolt of the same gereral design for the Atlas-Centaur Missile. However, this bolt had a much lower load capability (40,000 vs 393,000 lbs limit load). The design of the two NASA bolts was approached on a scale-up basis. As outlined in the presentation, most of the smaller design was successfully scaled-up, but in some areas scale-up problems were encountered.

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THE USE OF TLX ENERGY TRANSFER LINES
ON THE F-16 AIRCRAFT

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For presentation to the meeting of the
Pyrotechnics and Explosives Application Section
of the American Defense Preparedness Association
at Fort Worth, Texas on
27-28 September 1983

ACKNOWLEDGEMENT

The writer gratefully acknowledges the generous assistance of F. B. Burkdoll, G. B. Huber, and L. J. Enos of Explosive Technology, Inc., a subsidiary of OEA, in the preparation of this paper. The photographs of test items have been taken from Explosive Technology qualification test report number 4709(01) QTR. The photographs of TLX inspection equipment and the cost data in Table I were provided especially for use herein.

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THE USE OF TLX ENERGY TRANSFER LINES ON THE F-16 AIRCRAFT

1.0 INTRODUCTION

General Dynamics recently began using a new type of energy-transfer line in the crew-escape-initiation system on the F-16A/B aircraft. This new product, called TLX (for Thin Layer EXplosive)[1] by its manufacturer, Explosive Technology, is available in a variety of materials and configurations. This paper describes TLX in the form in which it has been qualified for use on the F-16 and briefly traces its evolution from the original Swedish product. It illustrates the current applications of TLX in the F-16 and gives the reasons why it has superseded two other types of linear-explosive lines. It summarizes the design requirements established by General Dynamics and the recently completed qualification-test program. Finally, it compares TLX with other energy-transfer lines used on the F-16.

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[1] TLX is a registered trademark of Explosive Technology, Fairfield, California

2.0 DESCRIPTION OF TLX

2.1 The Basic Product

TLX is one of a family of eight types of linear explosive lines, called Detonation Transfer Assemblies (DTAs), used in the F-16 crew escape initiation system. It is designated as the type ST (for Shock Tube) DTA because of the method by which energy is transmitted along the cord.

The basic element of TLX is a small-diameter tube that is made of plastic and whose inside surface is coated with fine particles of two or more reactive materials. When a strong shock is created at one end of the tube (as by the firing of a brisant primer, an SMDC tip, or similar explosive device), the reactive material is consumed by the advancing shock and thereby supplies sufficient energy to sustain the shock at a moderately high velocity (typically about 1750 meters per second). The output at the bare end of the tube is a 4,000 psi shock pulse, which attains peak pressure in approximately 25 microseconds, and a tongue of flame. This output can be utilized to initiate the reaction of one or more TLX lines that are proximate to the output end or to detonate an explosive charge in a specially designed end fitting that is attached to the TLX cord.

TLX was developed by Nitro-Nobel AB of Sweden in 1967. The original product (which they call Nonel) consists of a small tube (three millimeters outside diameter, one millimeter inside diameter) that is made of Surlyn (a copolymer of ethylene and vinyl) and whose inside surface is coated with particles of aluminum and HMX explosive. Several million feet of this product are produced each week in Europe and the United States for commercial use (mining, excavating, etc.).

2.2 The Product Developed for Use on the F-16

Tests of this commercial product showed that it was not suitable for use in the F-16 crew-escape-initiation system. A plastic that is resistant to higher temperature was essential. Overbraiding with wire was needed to provide adequate strength and crush resistance. End connections were required to permit the integration of the cord into a system. Explosive Technology was successful in finding a suitable plastic and in producing the necessary hardware. Figures 1 and 2 show a cross-section through the cord. Figure 3 shows the two types of end fittings (the

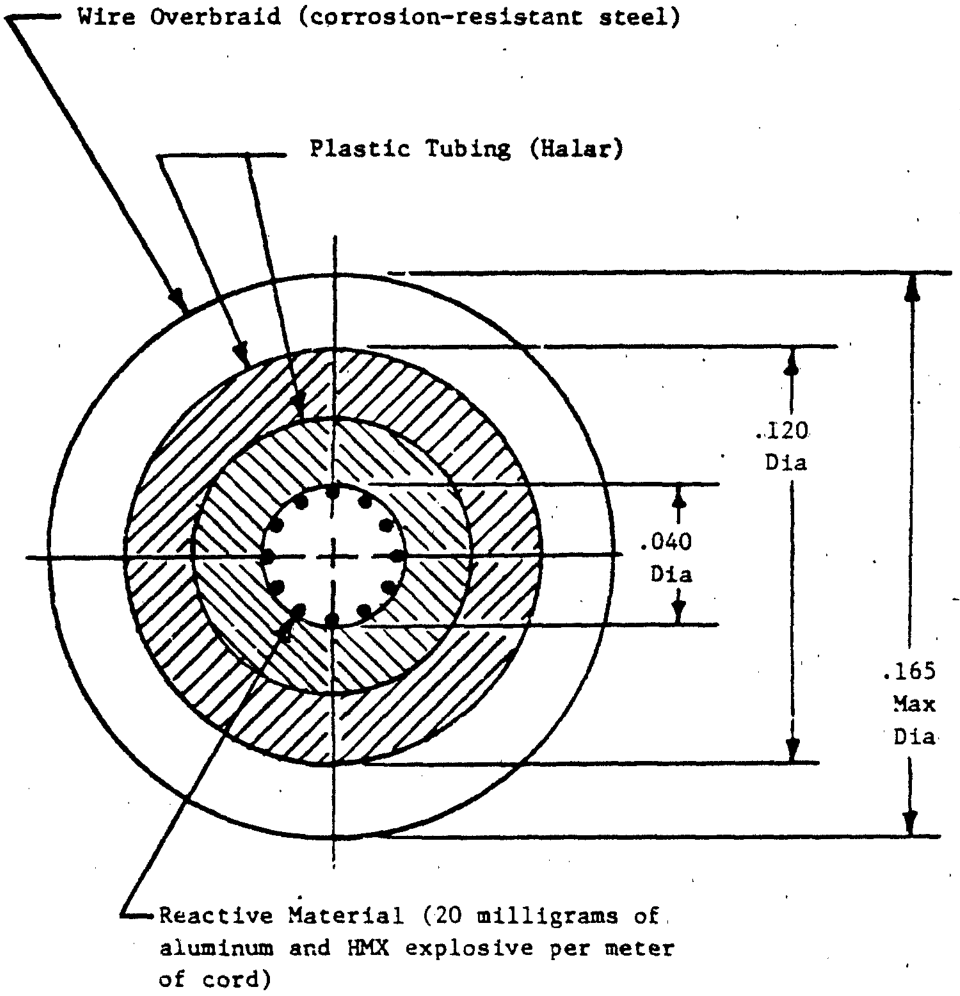
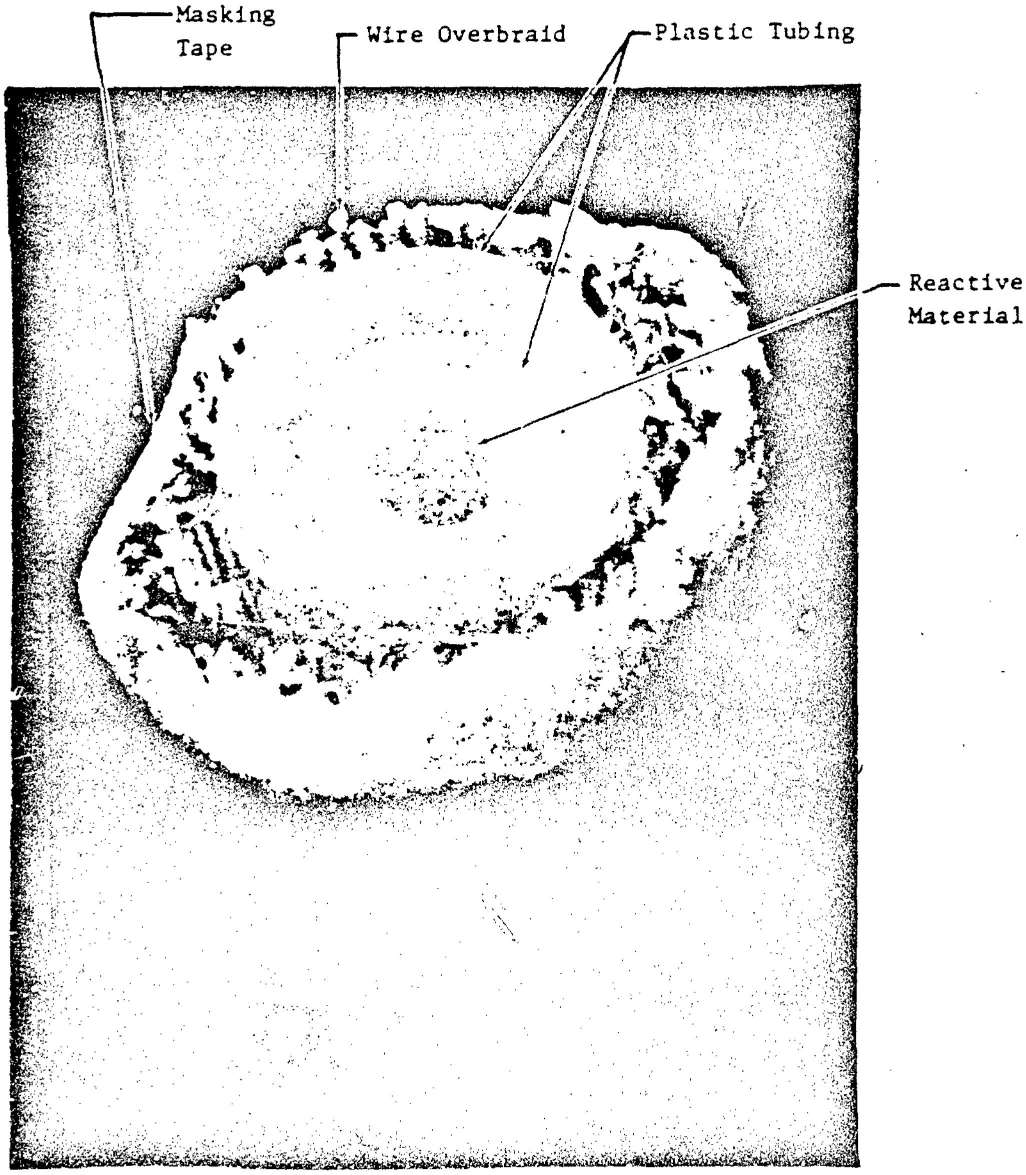
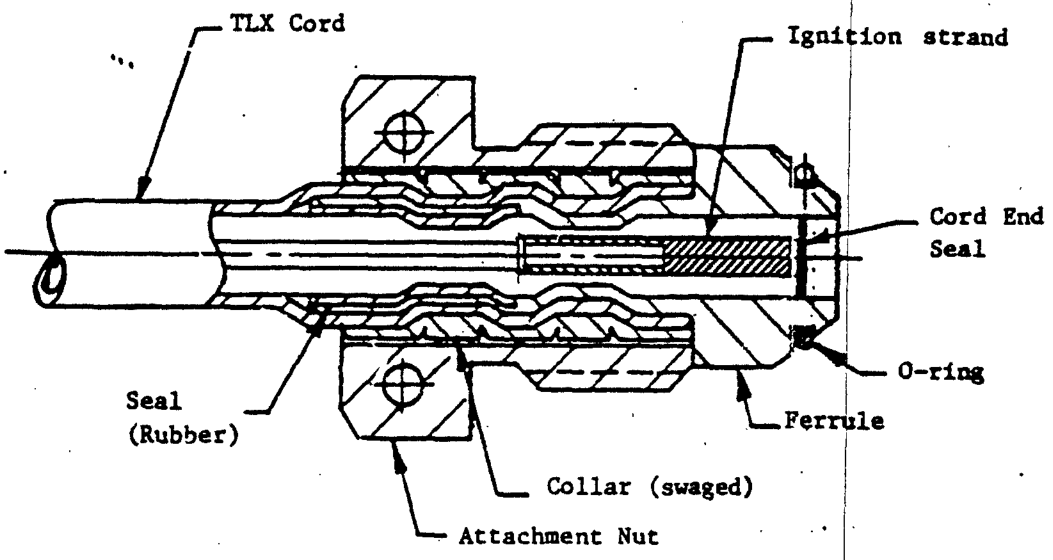


Figure 1 Cross-section of TLX Cord

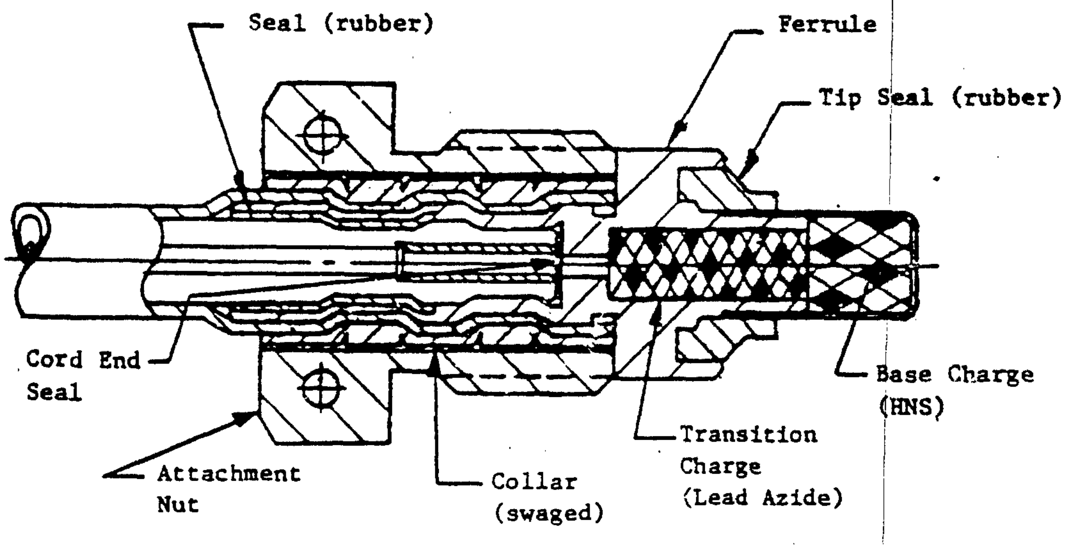


Note: Masking tape used to keep overbraid from unravelling.

Figure 2 Photograph of Section Through TLX Cord



TIPLESS END



STANDARD END

Figure 3 Cross-section Through Ends of TLX Assemblies "tipless" and the "standard") that have been developed at this time for F-16 usage. The components of a tipless end and the steps in their assembly onto the cord are shown in Figure 4.

The standard TLX end functions in the same manner as the tip of an SMDC (Shielded Mild Detonating Cord) or an FCDC (Flexible Confined Detonating Cord) line; therefore, a TLX line (a 16VK023 type ST DTA) having two standard end fittings can be used in place of a conventional SMDC or FCDC line. The standard end is also capable of detonating the tipless end of one or more TLX lines that are positioned properly with respect to it.

The output of a tipless TLX end will detonate one or more properly positioned tipless-end TLX lines. It is also capable of driving the gas-actuated firing pin in most gas-fired explosive devices. It will not, however, detonate the standard end of a TLX line or the tips of an SMDC or FCDC line. This circumstance permits the use of standard and tipless ends to make one-way transfer connections (Figure 5).

The TLX cord remains intact (the overbraid does not break) when the line is fired at any temperature between -65°F and 200°F. The cord remains attached to a tipless end. The cord always separates from the ferrule of a standard F-16 end fitting. Consequently, the designer of a system that employs TLX lines can, by the choice of types of end fittings, provide for the lines to remain attached to or to separate from line connections.

The TLX cord is extruded at a rate of several hundred feet per minutes and can therefore be produced in very long lengths (miles if desired). The reactive material is deposited on the inner surface of the plastic tubing while the heated plastic is emerging from the extruder. Explosive Technology has developed equipment that continuously measures the outside diameter of the extruded cord and the amount of reactive material deposited on its inner surface (see Figures 6 and 7). If the diameter of the cord or the quantity of reactive materials falls outside the specified upper or lower limits, a machine (Figure 8) marks the nonconforming cord and signals the operator. The nonconforming portion of the overall length of cord is then cut from the acceptable cord and discarded.

Other features of TLX lines are discussed in subsequent sections of this paper.

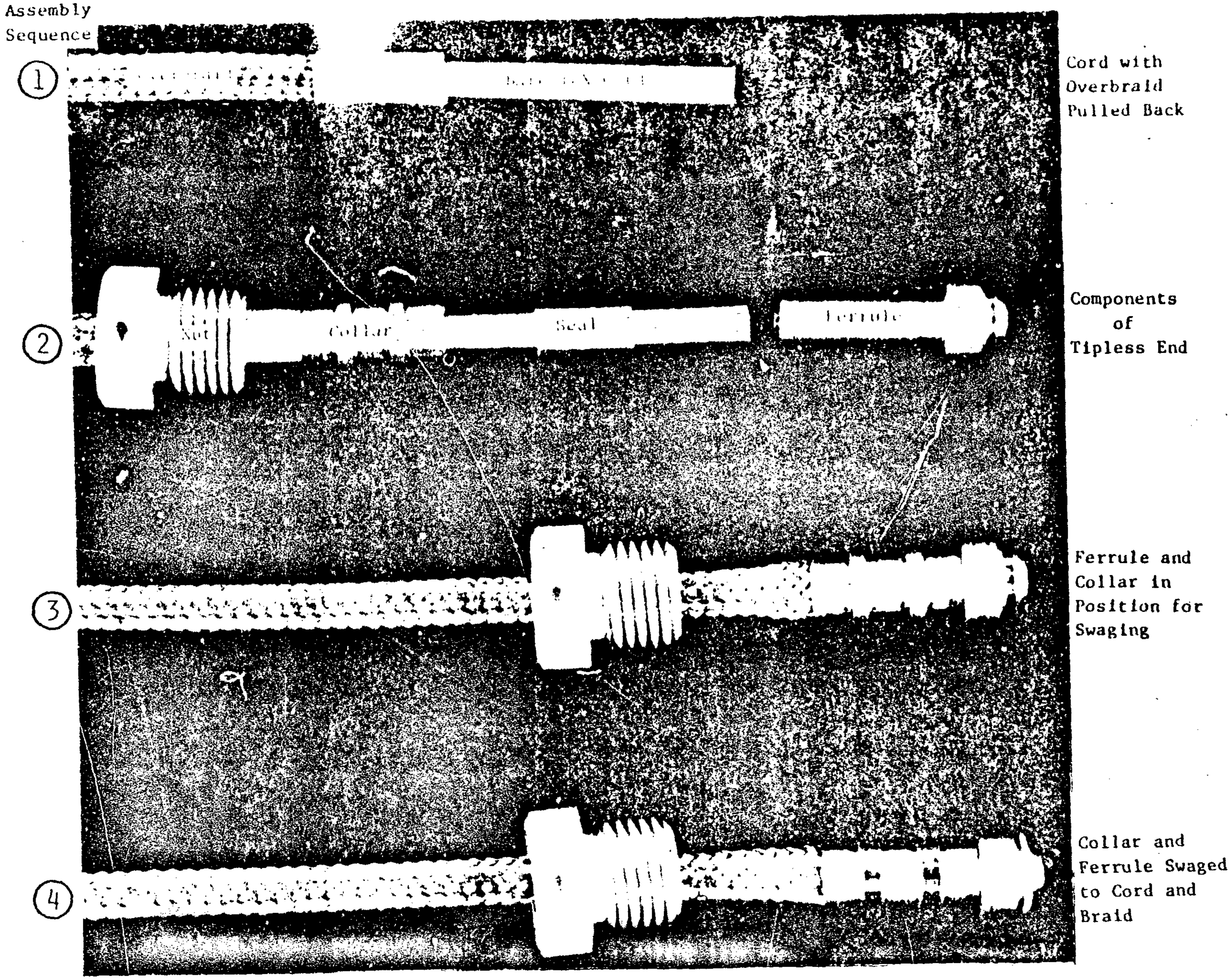
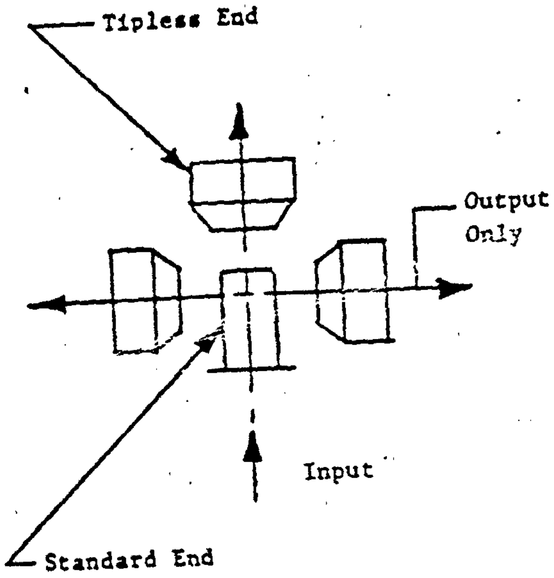
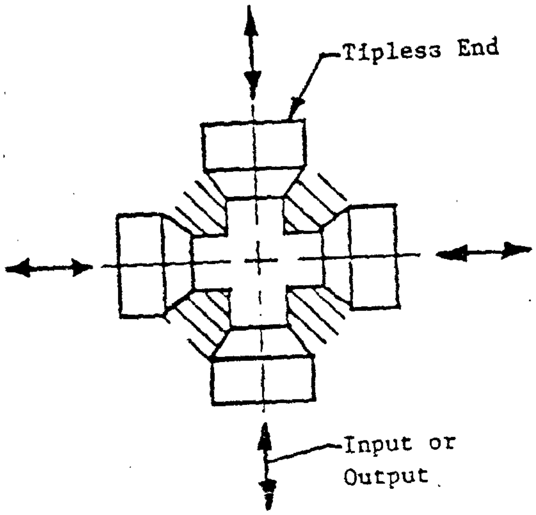


Figure 4 Attaching Tipless End to TLX Cord



Output from tipless end will not detonate tip of standaru end

One-way Transfer



Output from any tipless end will detonate all other properly positioned tipless ends in connection

All-way Transfer

Figure 5 Detonation Transfer Among Ends of TLX Lines

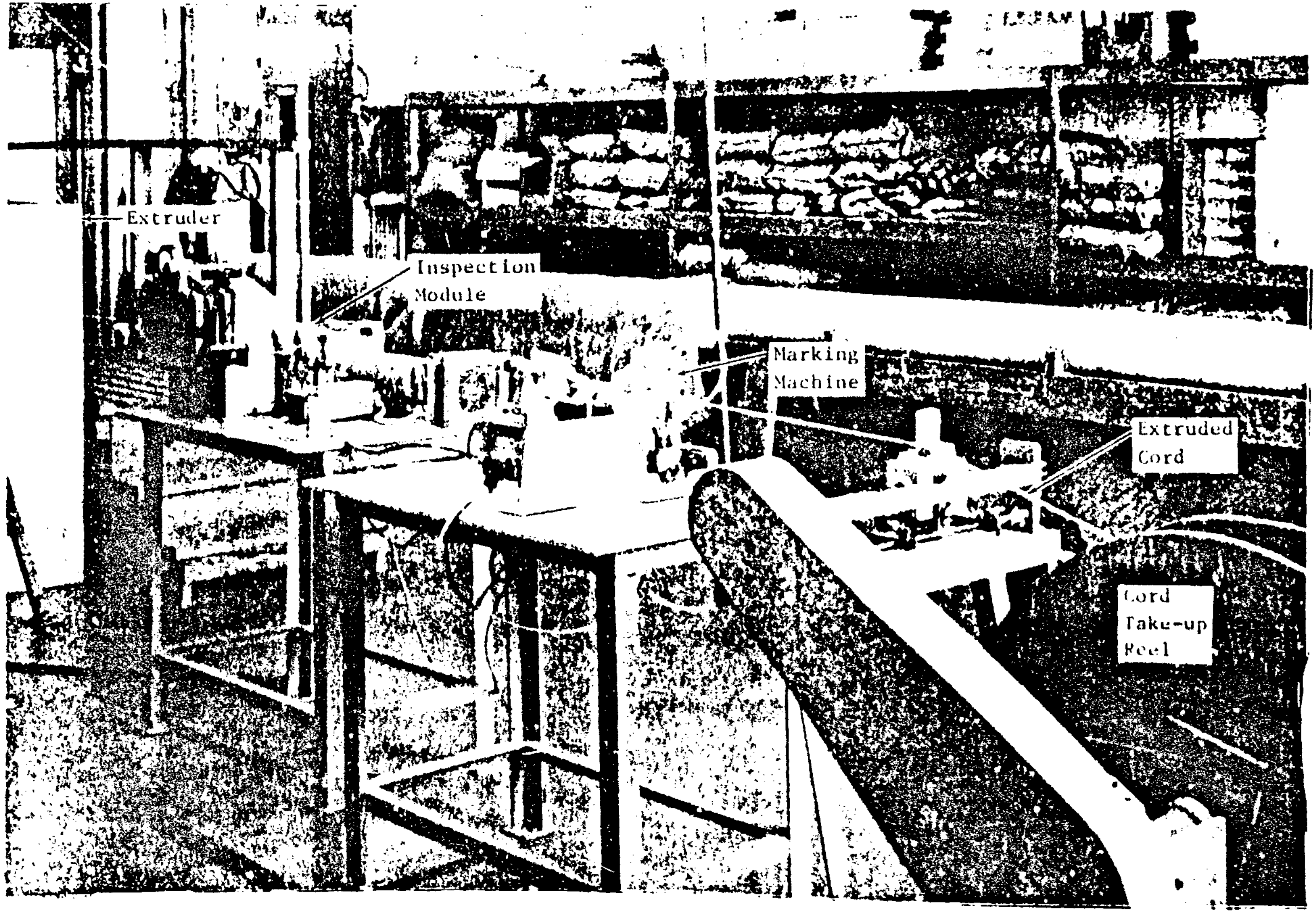
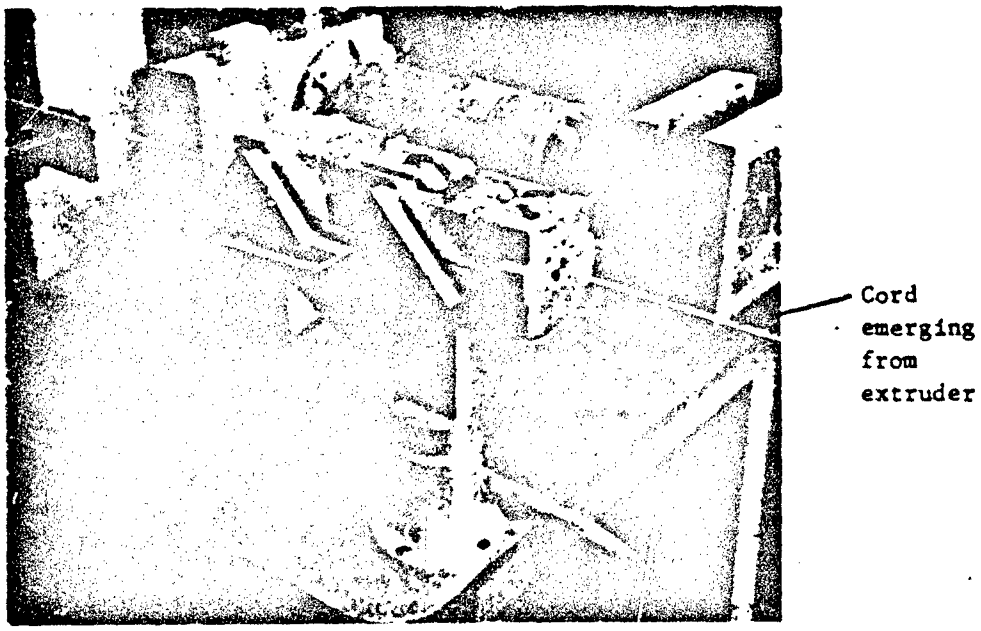
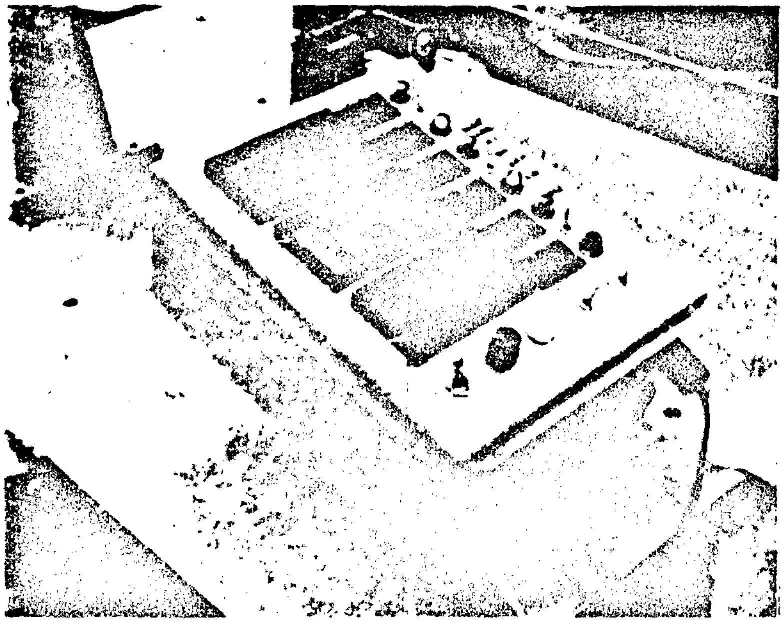


Figure 6 Overall View of System That Measures Diameter and Reactive-Material Content of Extruded TLX Cord

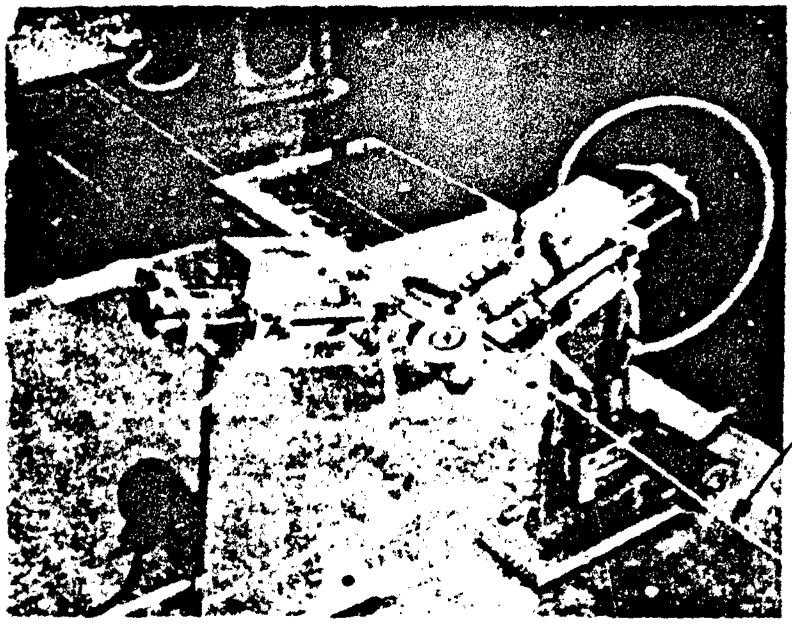


Inspection module that measures diameter of plastic cord and quantity of reactive material in cord. Infrared scanners measure amount of light passing through cord.



Display module that shows diameter of cord and a number that is related to quantity of reactive material in cord.

Figure 7 Equipment for Measuring Diameter and Reactive Material Content of TLX Cord



Machine marks cord if its outside diameter or reactive-material content falls outside the specified limits.

Figure 8 Machine for Marking Nonconforming TLX Cord

3.0 APPLICATION OF TLX LINES ON THE F-16 CANOPY

3.1 Use of DTAs in the Canopy Jettison System

Three of the major explosive devices in the F-16A and B canopy-jettison systems are installed in the canopy. As can be seen in Figure 9, these devices (two rocket motors and an explosive bolt) are interconnected with the fuselage-mounted portion of the crew-escape-initiation system by several types of DTAs. A type F (flexible) DTA (Figures 10 and 11) was utilized between a two-way DTA connector mounted on each side of the aircraft fuselage and a three-way DTA connector mounted on each side of the canopy near the canopy pivot point. A type S (standard) DTA was utilized between each of the two three-way connectors and one of the two rocket motors (Figures 11 and 12). These four DTAs were recently replaced with TLX lines (type ST DTAs), as shown in Figures 13 and 14, for several reasons.

3.2 Replacement of Type F DTAs with TLX Lines

The two major design requirements for the DTA that interconnects the two-way and three-way connectors at the canopy pivot point are (a) that the DTA cord withstand 30,000 cycles of flexure in the arrangement shown in Figure 15, and (b) that the cord separate from one or both of end fittings when the DTA is fired (so that the canopy will be disconnected from the fuselage). The type F DTA (which is conventional FCDC except that it contains 7 grains per foot of HNS explosive instead of 2.5 grains per foot) satisfied the second requirement because the cord disintegrates when the DTA is fired. The first requirement was not met, however, because the lead-sheathed cord in the center of the assembly (Figure 11) would break after 5,000-6,000 cycles of flexure. Consequently, it was necessary to limit the service life of the type F DTA to 2.5 years instead of 15 years as intended. Also, the cost of this type DTA is relatively great (see discussion of costs in Section 5.0 of this paper). The TLX line that has replaced the type F DTA has withstood, without observable damage, 250,000 cycles of flexure in the arrangement shown in Figure 15; therefore, it can be used for the desired 15-year period. In addition, its cost is less than one-third of that of the type F DTA. As a result of these factors, the Air Force will realize an 18:1 cost advantage in the procurement of hardware plus a savings in labor by avoiding five replacements of the DTAs over the 15-year operational life of the aircraft.

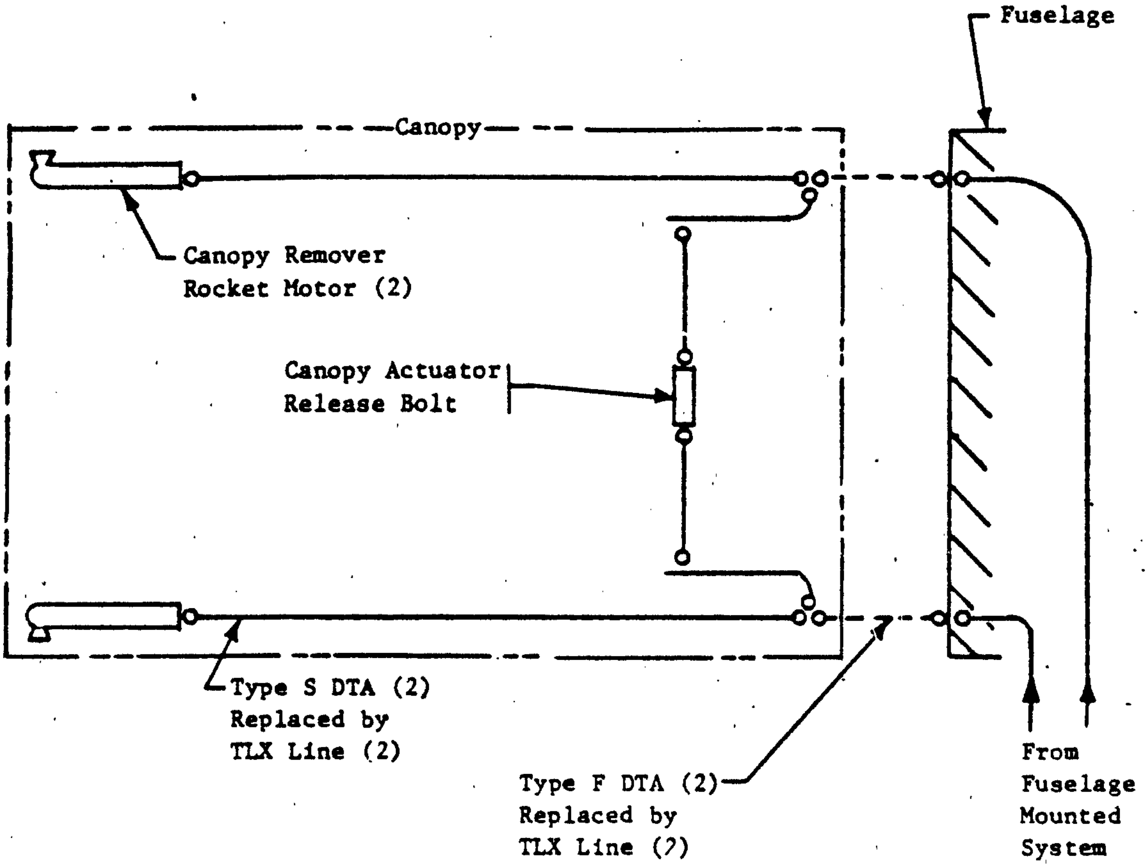


Figure 9 Schematic of Canopy-Mounted Portion of F-16A Canopy-Jettison System

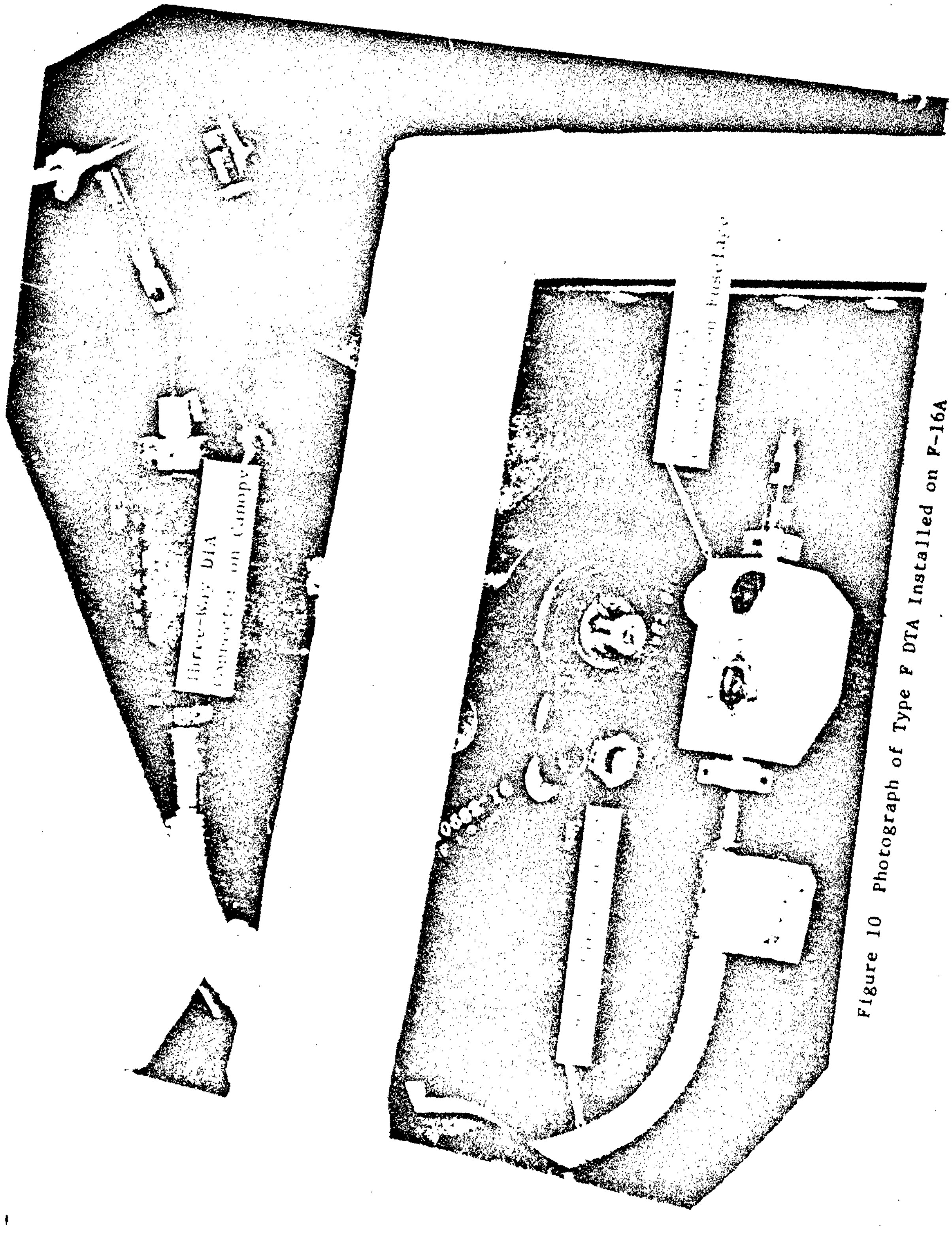
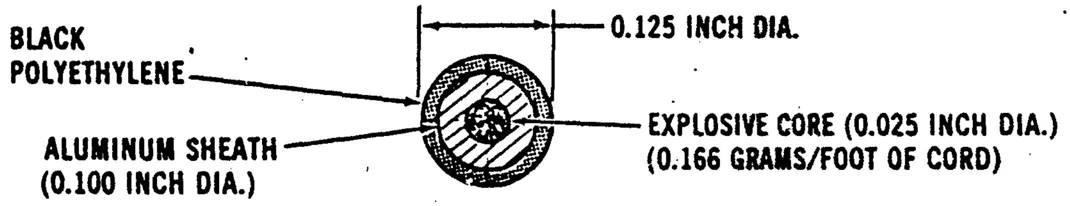
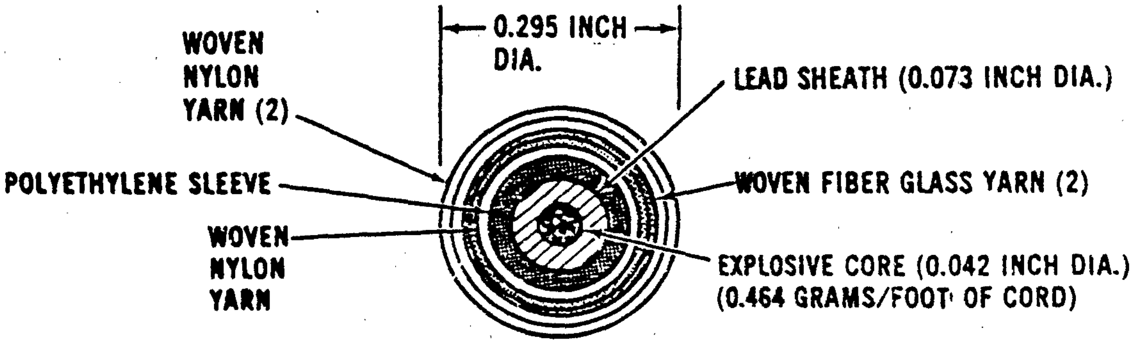


Figure 10 Photograph of Type F DTA Installed on F-16A



The type S DTA is semirigid. It is formed to the desired shape before it is installed. It disintegrates when it is detonated.

Cross-Section Through Type S (Standard) DTA



The type F DTA is identical to FCDC (flexible confined detonating cord) except that it contains 7 grains of explosive per foot of cord. It disintegrates when fired.

Cross-section Through Type F (Flexible) DTA

Figure 11 Cross-sections of Types F and S DTAs

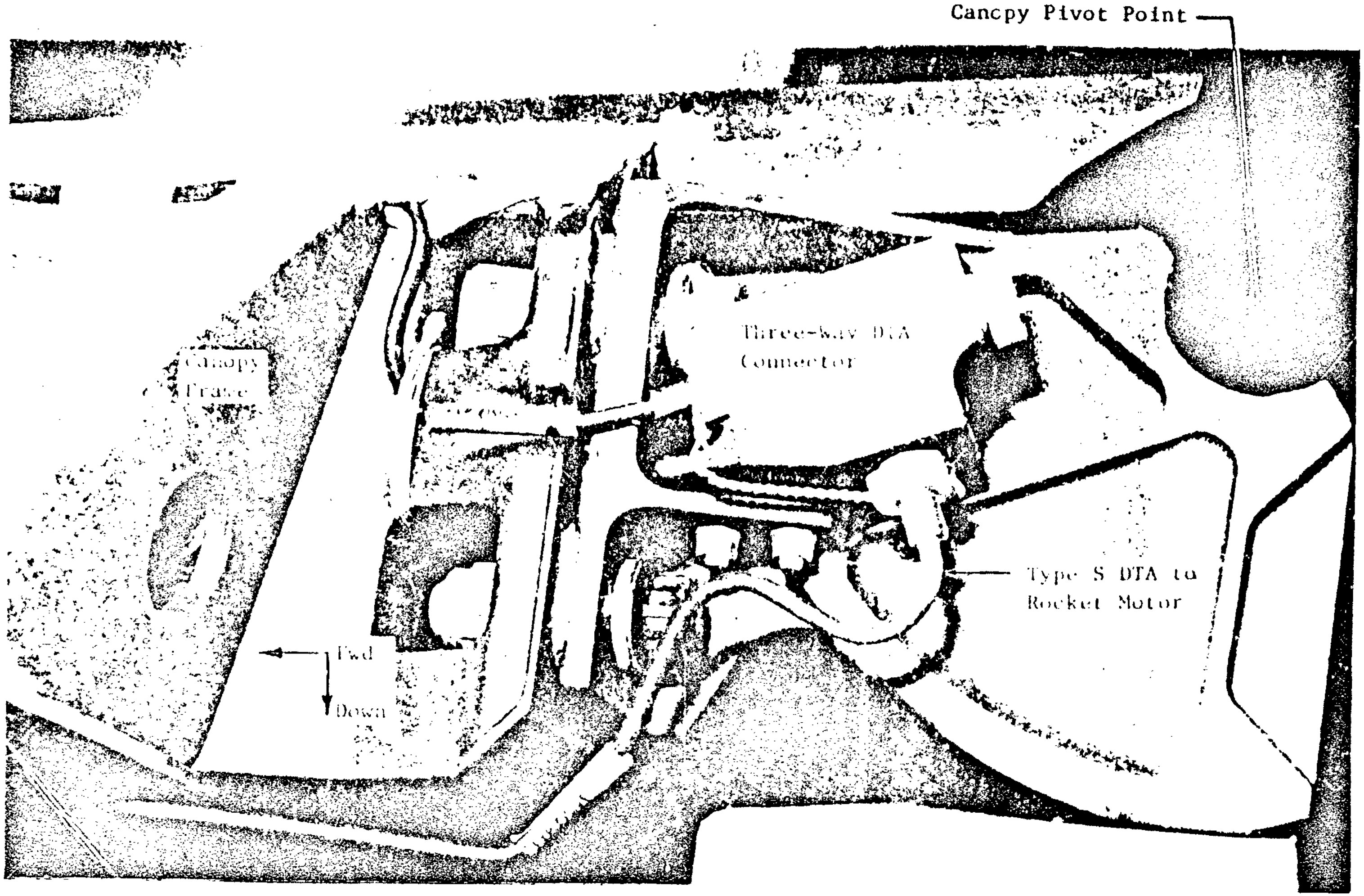


Figure 12 Photograph of Three-Way DTA Connector With Type S DTA Attached

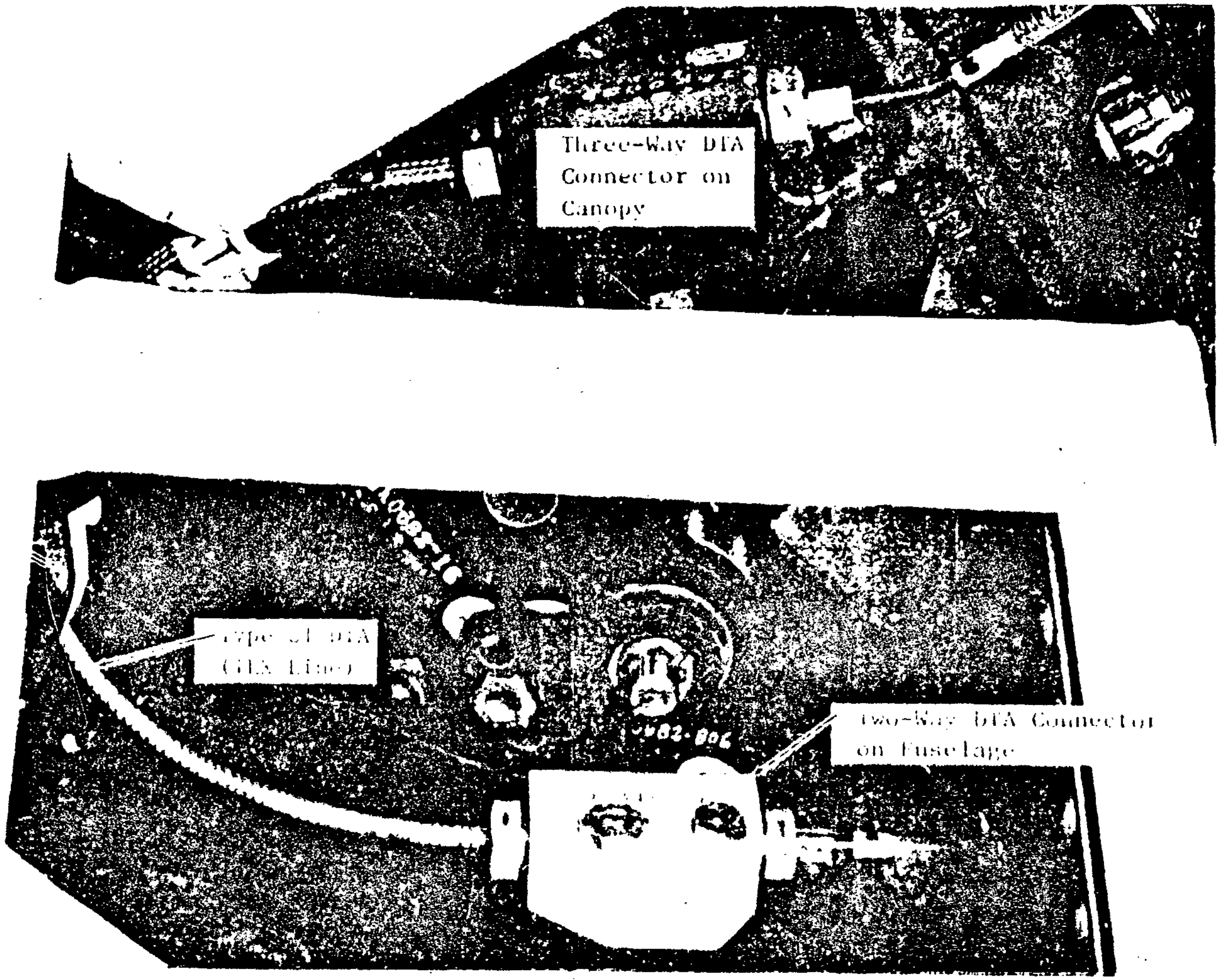


Figure 13 Photograph of Type ST DTA (TLX Line) Installed on F-16A

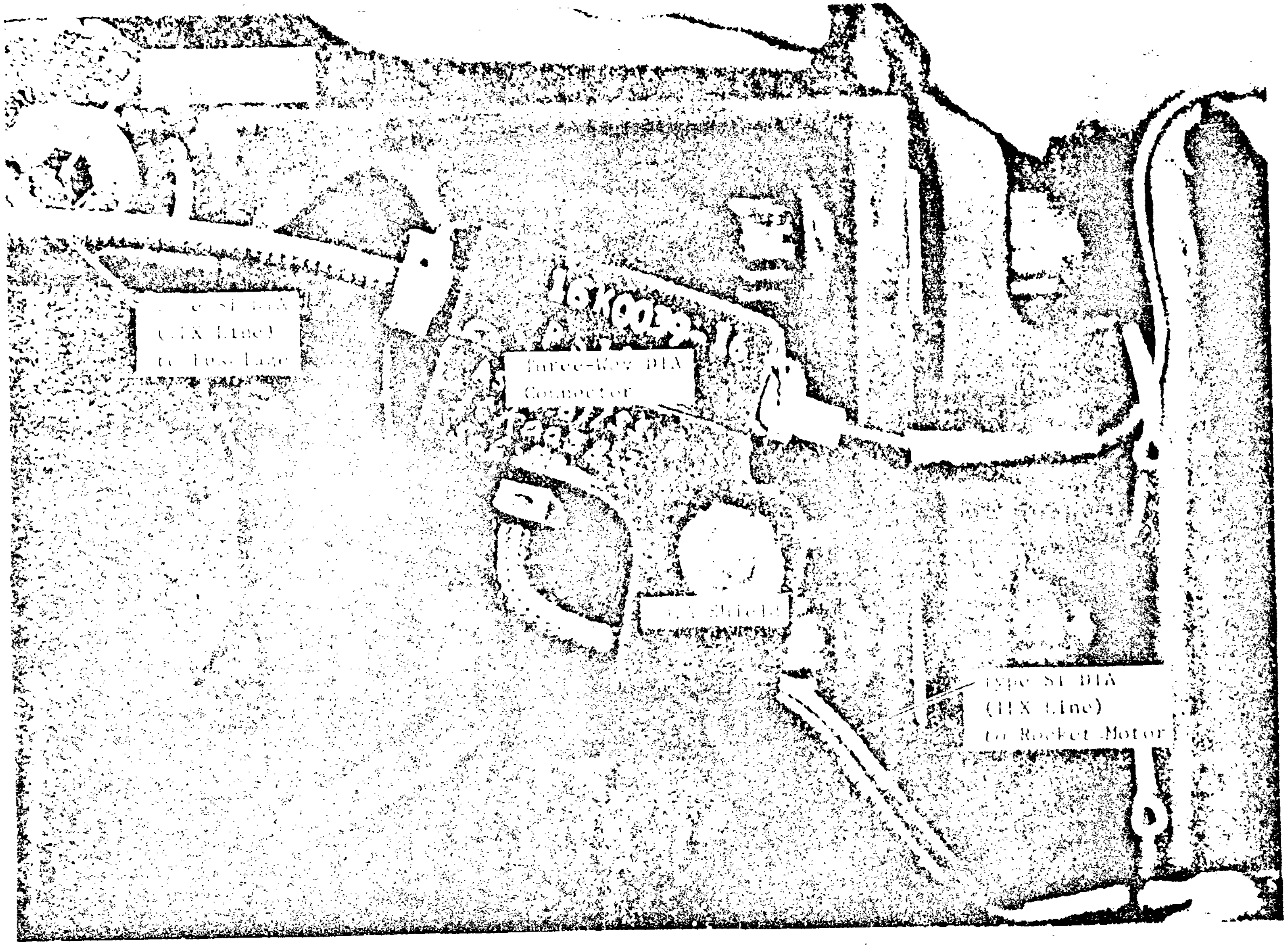
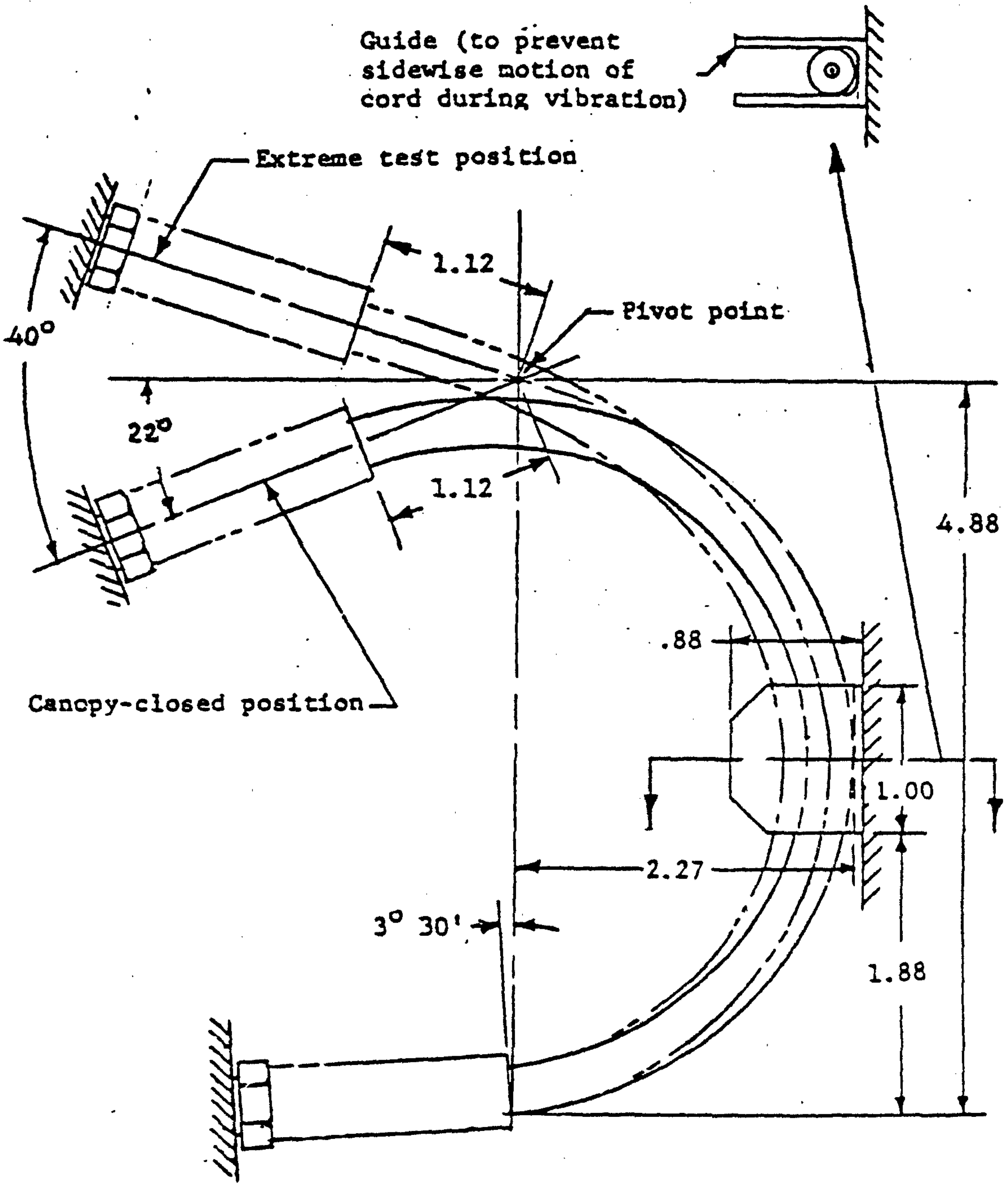


Figure 14 Photograph of Installation of TLX Lines at Three-Way DTA Connector



The type F DTA, mounted as shown above, was required to withstand, without damage, 30,000 cycles of flexure. One cycle consisted of moving from the canopy-closed position to the extreme test position and back to the canopy-closed position. It would withstand only 5,000 cycles before the lead-sheathed cord in it cracked.

Figure 15 Flexure Requirements for Flexible DTA

3.3 Reasons for Replacing Type S DTA with TLX Lines

The type S DTA that interconnects the three-way connector and the rocket motor is suitable for use over the 15-year operational life of the airplane, but it proved to be very susceptible to damage, especially near its connection to the three-way DTA connector on the F-16A canopy (Figure 12). Because the tipless end of the TLX line is much shorter than is the end of the type S DTA (Figure 16), it was possible to redesign the three-way connector to add a DTA shield (Figure 14) to protect the end of the DTA from damage caused by careless handling of the canopy and during work performed near the canopy pivot point. Also, the TLX cord is much more rugged than is the cord of the type S DTA (see discussion in Section 5.0 of this paper) and is therefore much more resistant to being damaged by wrenches, screwdrivers, and other tools employed by workers in maintaining the canopy. In addition, the TLX line costs less than does the type S DTA.

Consideration is being given to using TLX lines in several other places on the F-16.

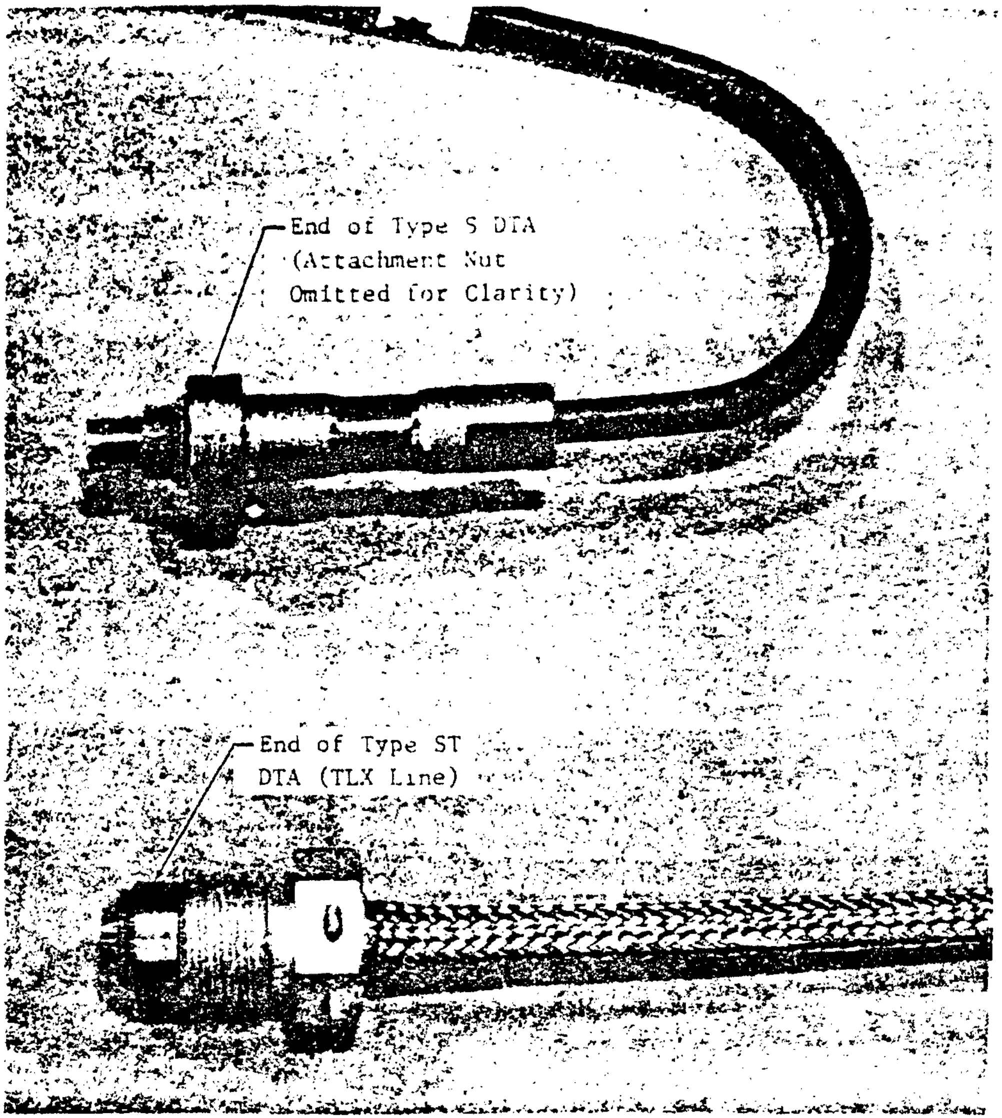


Figure 16 Photograph of Standard End of Type S DTA and Tipless End of TLX Line

4.0 THE QUALIFICATION OF TLX FOR USE ON THE F-16

4.1 The Formal Test Program

A plan was developed for qualifying TLX lines for use not only in the F-16A and B canopies in the locations described in Section 3.0 but in many other places on the airplane. This program, outlined in Figure 17, included not only the conventional environmental tests (humidity, salt-fog, and temperature cycling) and the usual structural tests (six-foot drop, forty-foot drop, vibration, and shock) but the following additional tests:

a. Humidity was combined with the high temperature portion of each cycle of the temperature cycling tests (Figure 18) to make certain that the TLX line is adequately sealed against moisture under the most adverse operational conditions.

b. Flexure tests (60,000 cycles) were performed to verify the ability of the TLX cord to withstand at least twice the flexing anticipated to occur during the life of the F-16.

c. Joint-integrity and joint-failure load tests were performed for two purposes: to determine that the line will meet the 60-pound tensile-force requirement established in the procurement specification and to find the tensile force at which the line will fail.

d. Damage tolerance tests (Figure 19) were performed to determine how large a crushing load can be applied to the TLX cord before the plastic tubing is ruptured or a propagation failure is induced.

Following the environmental tests six groups of ten lines were fired in the functional-test arrangement shown in Figure 20, two at -65°F, two at ambient temperature, and two at 200°F. This test arrangement was designed not only to demonstrate the capability of lines that had experienced various environments to function properly but also to demonstrate:

a. The capability of TLX cord to sustain a shock wave around a small radius (0.34-inch) bend.

b. The capability of a standard end to fire several tipless ends (Figure 21).

c. The capability of a tipless end to fire several other tipless ends (Figure 22).

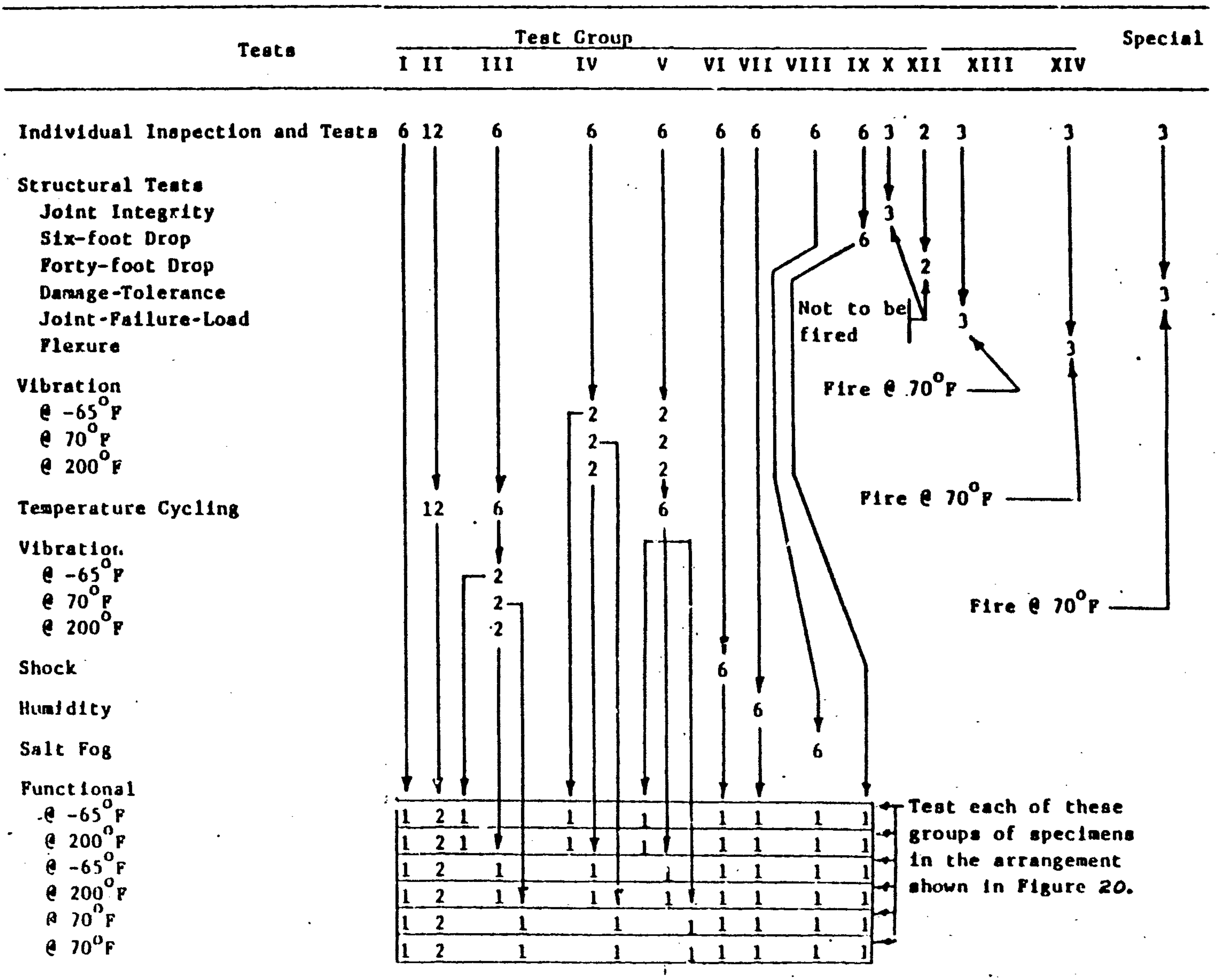
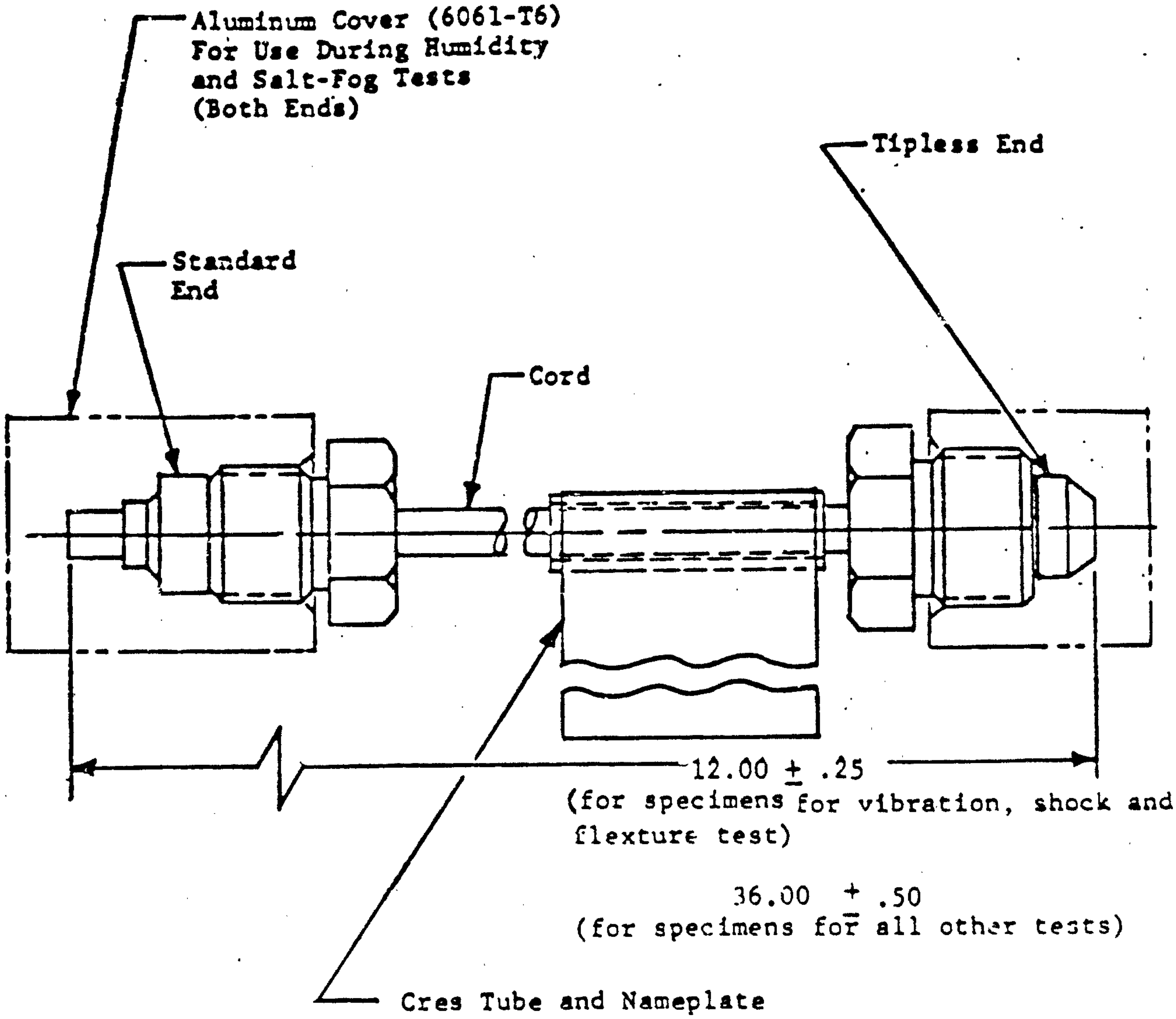
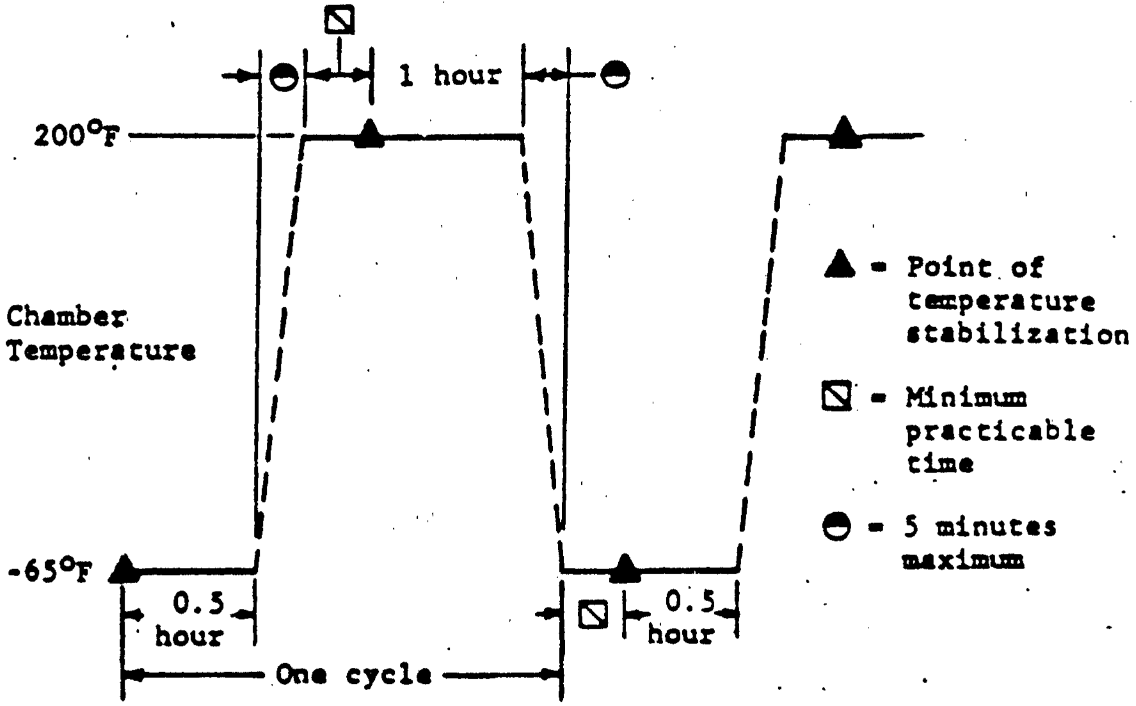


Figure 17 Plan for Qualification Tests of Type ST DTA (TLX Lines)
Sheet 1 of 2



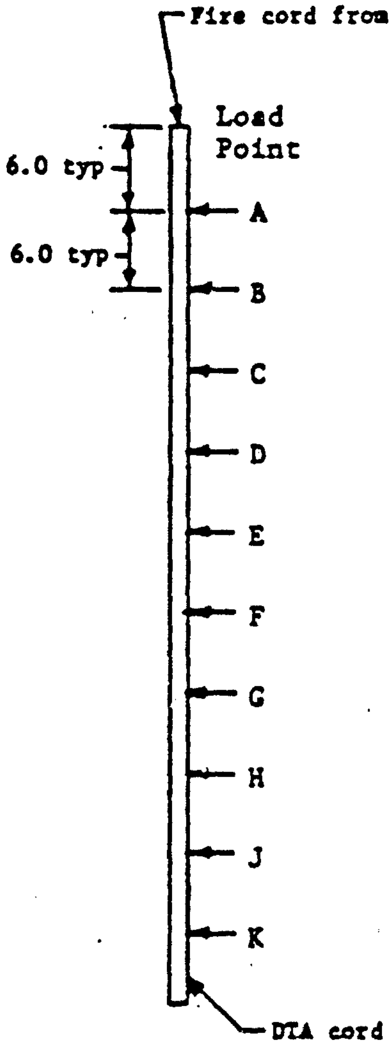
Test Specimens

Figure 17 Plan for Qualification Tests of Type ST DTA (TLX Line)
Sheet 2 of 2

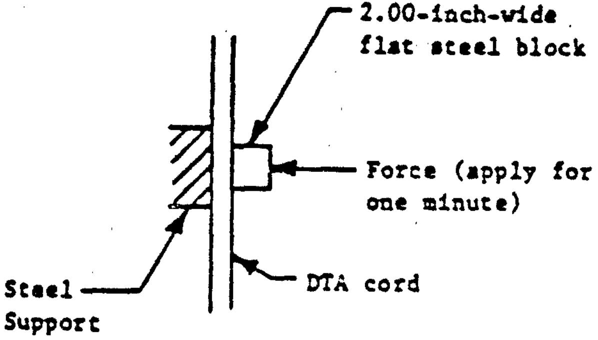


Each test specimen was subjected to 50 of the temperature cycles shown above. The exposure at 200°F was accomplished in a humidity chamber. The relative humidity in the chamber was raised, as rapidly as possible after the specimens had been placed in the chamber, to at least 85 percent. The one-hour exposure period at 200°F began after the relative humidity had reached a value of at least 85 percent. The relative humidity was increased as much as possible during the one-hour period. Typically it reached 93 percent by the end of the cycle.

Figure 18 Description of Temperature-Humidity Cycling Test of TLX Lines



Load Point	Force (lbs)
A	10
B	20
C	30
D	40
E	50
F	60
G	80
H	100
J	125
K	150



Method of Application of Force

Three pieces of overbraided TLX cord were subjected to the crushing loads listed above. Visual examination of the tested lines disclosed no evidence of physical damage (cracking, crushing, etc.). The three pieces of cord were then initiated from the end indicated above. Each of the lines functioned normally over its entire length.

Figure 19 Damage Tolerance Test of TLX Cord

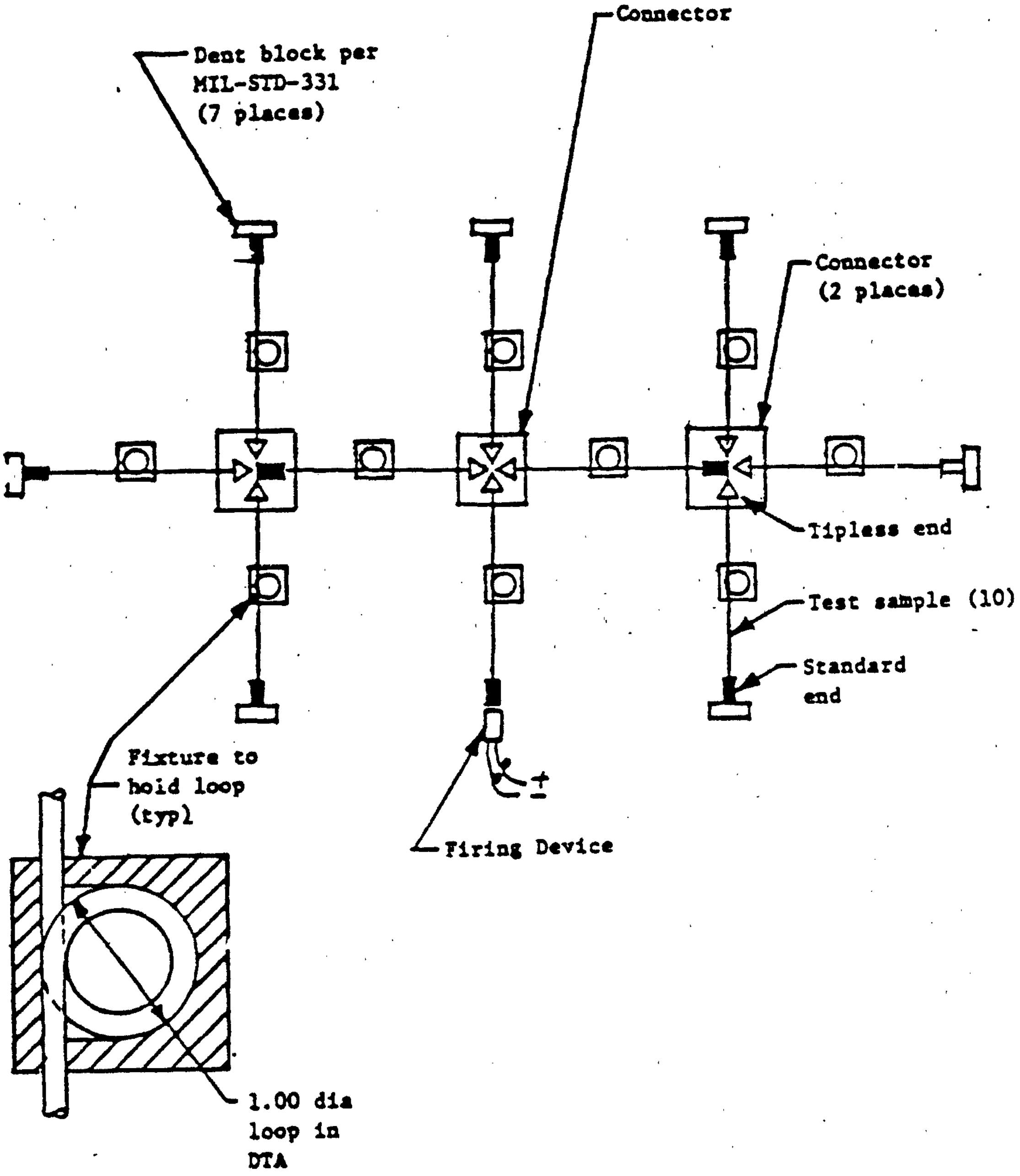
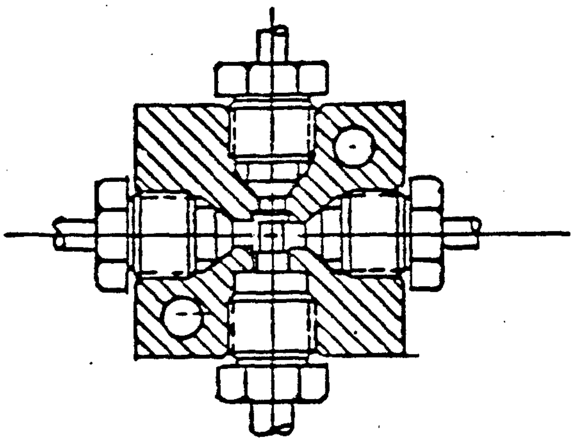
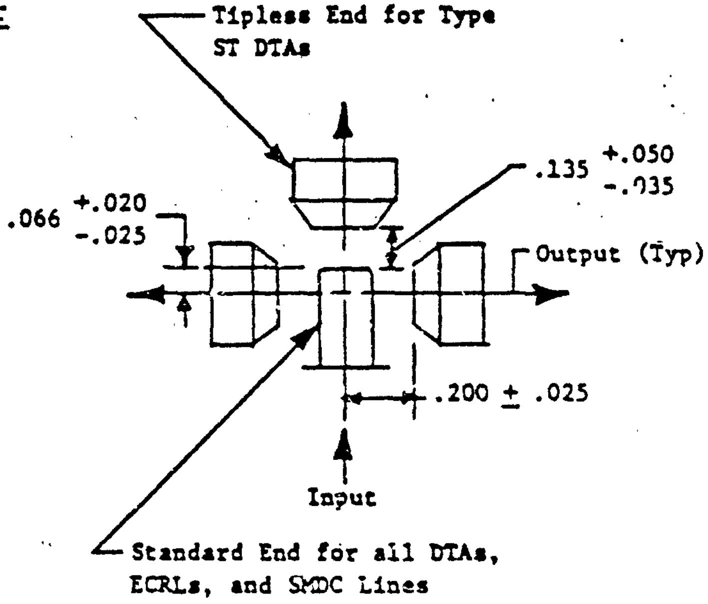


Figure 20 Arrangement for Functional Tests of Type ST DTA (TLX Line)



Typical 4-Way Connector

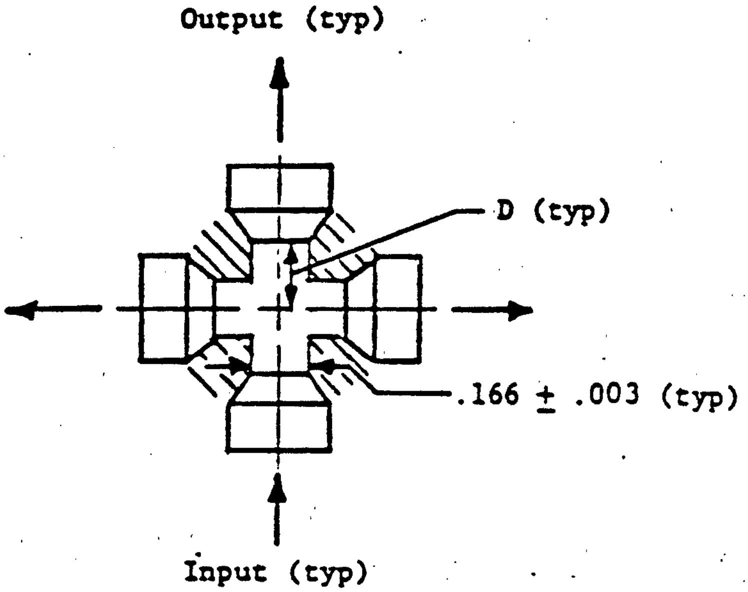


Relationship Among Standard And Tipless Ends

The standard end is to be capable of properly initiating one or more tipless-end DTAs positioned radially about the tip of the standard-end DTA as shown. It must also be capable of properly initiating a single tipless-end DTA that is positioned axially as shown.

Note: The tip-to-tip spacings shown above are taken from General Dynamics Specification 16ZK023D. These spacings do not represent the limits over which the output of a standard end will reliably initiate the tipless ends of type ST DTAs (TLX lines).

Figure 21 Relationship Among Standard and Tipless Ends of TLX Lines for Assured Detonation Transfer



Tip Size	D (inches)
1	.150 .100
2	.165 .115
3	.190 .140

Note: The tip-to-tip spacings shown above are taken from General Dynamics Specification 16ZK023D. These spacings do not represent the limits over which the output of a tipless end will reliably initiate the tipless ends of type ST DTAs (TLX lines).

Figure 22 Relationship Among Tipless Ends of TLX Lines for Assured Detonation Transfer

All of the qualification tests were successful. Compliance with all specific design requirements was demonstrated. In addition, the following useful data were obtained:

a. The tensile forces required to fail three TLX lines were 255, 260, and 260 pounds.

b. The maximum load (150 pounds) applied during the damage-tolerance test did not prevent the normal functioning of the line.

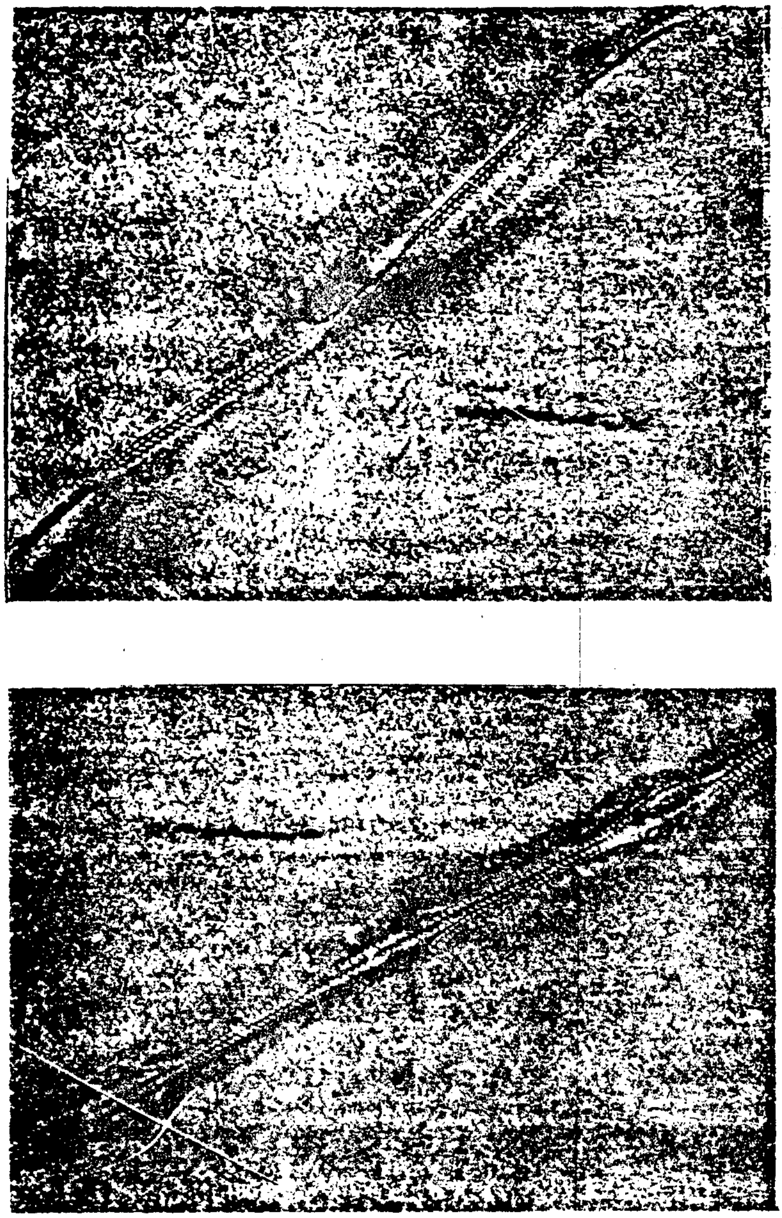
c. Three lines that had been subjected to a 205-pound tensile load were not visibly damaged and fired normally.

4.2 Informal Tests

Explosive Technology performed some additional, informal tests in conjunction with the formal qualification tests to obtain information of use to persons concerned with the design and safety of TLX lines and of systems that contain TLX lines. Some of these tests and the results thereof are described briefly below.

a. Impact Drop Tests. One two-foot long length of the TLX cord was subjected to an impact load of 2.5 pounds dropped from a height of six feet. A second length of cord was subjected to an impact load of 20 pounds dropped from a height of 42 inches. Each test was repeated three times in three adjacent locations on each piece of cord. The purpose of these tests was to determine if the cord would initiate when subjected to such severe impacts. Neither of the cord specimens initiated. Both specimens suffered damage (Figure 23).

b. Autoignition Test. One TLX assembly with one standard and one tipless end and three one-foot-long cord specimens were placed in an oven preheated to 300°F and held at that temperature for ten minutes after the oven stabilized. The oven temperature was increased in 25°F increments and stabilized at each of the temperature plateaus for ten minutes until the temperature reached 400°F. None of the specimens ignited. One cord specimen was removed and functioned. It propagated completely. The remaining specimens were then subjected to a second autoignition test in an oven with a faster thermal response. The temperature was increased in 50°F increments from 400°F to 600°F. In approximately 25 minutes, at 568°F, a small "pop" type noise was heard. The temperature reached 600°F in approximately 35 minutes, at which time the specimens were removed from the environmental



Photographs of the effects on TLX cord of three impacts of a twenty-pound weight dropped from a height of forty-two inches. The cord was not initiated.

Figure 23 Results of Impact Tests of TLX Cord chamber. The end of the cup on the high-explosive end of the TLX assembly had popped out, but the remainder of the line was intact. None of the cord specimens detonated. The Halar sheath material had seeped through the stainless steel braid and was somewhat charred (Figure 24).

c. Gasoline Fire Test. Three pieces of TLX cord and one TLX assembly (with one standard and one tipless end without any protector caps) were placed approximately one inch above a pool of gasoline in a shallow pan. The gasoline was ignited. As was expected, the DTA line detonated approximately 20 seconds after the gasoline was ignited. The cord specimens did not detonate. The Halar plastic melted through the stainless steel braid and was severely charred.

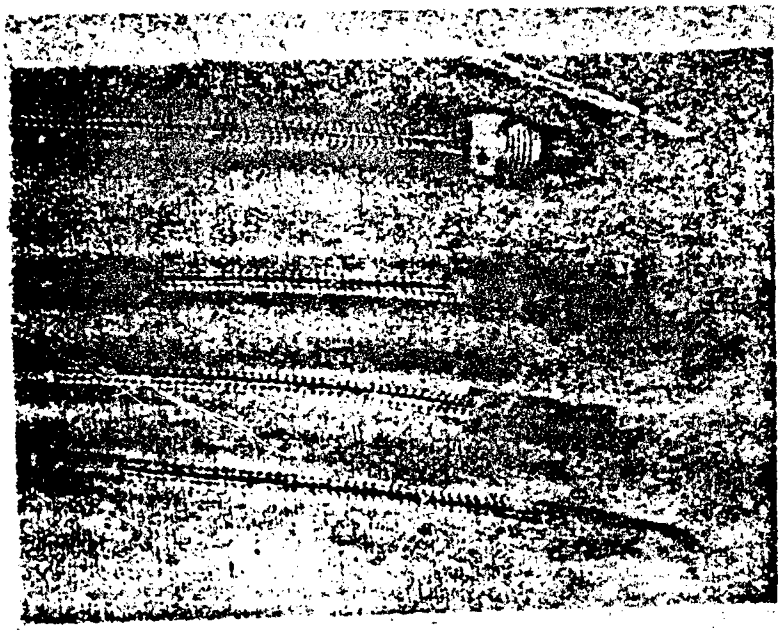
d. Drill-Through Test. Two pieces of TLX cord were subjected to a test in which a 0.095-inch diameter drill was pushed through each piece in three places. In one piece the drill was turning at 4250 revolutions per minute (rpm); in the other specimen it was turning at 8250 rpm. Neither of the specimens was initiated (Figure 25).

e. Propane Torch Test. Five two-foot-long pieces of TLX cord were burned in the middle with a propane torch until the Halar plastic had completely melted through the stainless steel braid and charred into a hard crust. None of the pieces of cord was initiated.

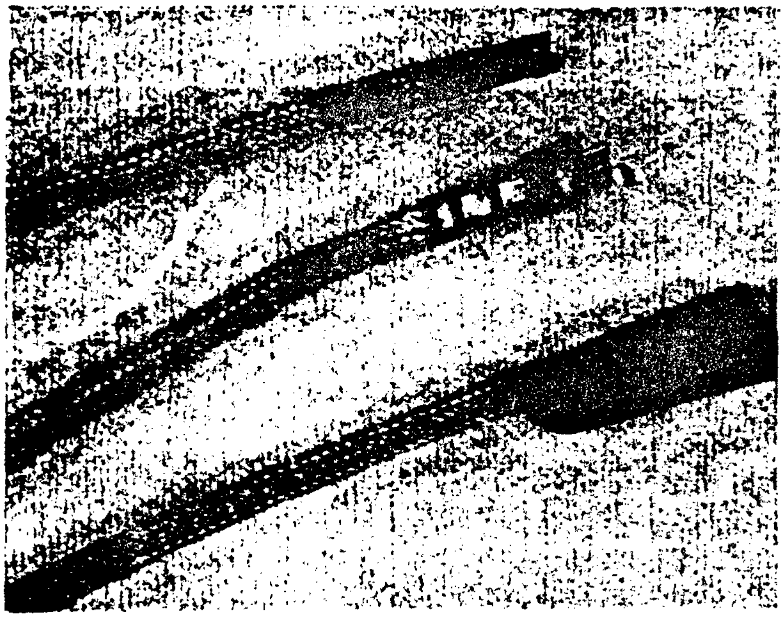
f. Acetylene Torch Test. Five, two-foot long pieces of TLX cord were subjected to the flame of an acetylene torch until the stainless steel braid was severed. The plastic sheath material was completely melted and charred in the vicinity of the flame. None of the pieces were initiated.

g. Electric Arc Welder Test. Five, two-foot long pieces of TLX cord were placed on a metal plate, and an electric arc was struck such that it would sever the specimens. Significant arcing and sparking occurred. The stainless steel braid was burned through in several places. None of the pieces were initiated.

h. Flexure Tests at Temperature Extremes. Six TLX lines (having one standard and one tipless end) were subjected to the full flexure test required by the procurement specification except that three of the assemblies were kept at a temperature of -65°F and three at a temperature of 200°F throughout the 60,000 flexure cycles. There was no evidence of any cracking

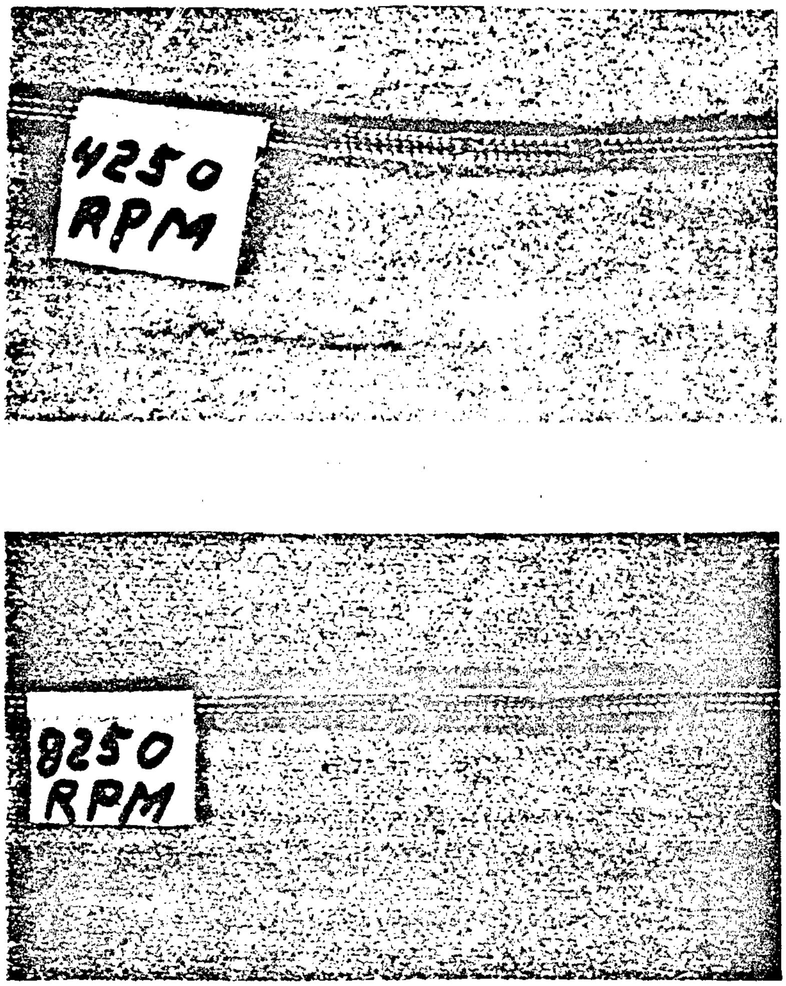


Autoignition Specimens After Exposure Up to 400°F. Tape was placed over ends so if the TLX cord ignited, the tape would be blown open. One TLX cord specimen was successfully functioned after this exposure. The remaining specimens were subjected to a temperature of 600°F.



Autoignition Specimens After Exposure Up to 600°F. Note the plastic oozing through the stainless steel braid. The end of the booster cup hinged open after a "pop" at 568°F.

Figure 24 Results of Autoignition Tests of TLX Line and Cord



Appearance of TLX cord after it was drilled through by an 0.095-inch-diameter drill at the speeds indicated. The cord was not initiated.

Figure 25 Results of Drill-Through Tests of TLX Cord or splitting of the plastic tube, breaking of the overbraid, or failure of any of the end fittings. The lines functioned normally when fired.

4.3 Test Report

The results of both the formal qualification tests and the additional, informal tests are contained in Explosive Technology report number 4709(01) QTR.

5.0 COMPARISON OF TLX WITH OLDER ENERGY TRANSFER LINES

TLX lines can be used in most of the applications for which the older types of energy-transfer lines (SMDC, FCDC, and the various types of F-16 DTAs) have been used. It may - because of its small size, low cost, great flexibility, ruggedness, or other peculiar properties - be suitable for applications for which none of the older types of lines could or would have been considered. Some of the attractive properties of TLX lines are discussed below.

a. Producibility. TLX cord can be produced at high manufacturing speeds (several hundred feet per minute) and in unlimited lengths (miles if desired), whereas all of the metal-sheathed cords must be manufactured at very low speeds (typically several feet per minute) and in limited lengths (typically several hundred feet maximum). The tipless-end fittings, which should be the type most commonly used, are simple and easily attached to the cord (Figure 1). Consequently, delivery times and manufacturing rates can be better than delivery times and manufacturing rates for most of the older linear-explosive products.

b. Low Cost. A comparison of the costs of producing a quantity of TLX lines and the same quantity of several other types of F-16 DTAs (including SMDC and FCDC lines) is presented in Table I. The cost of conducting lot-acceptance tests of each type of line in accordance with General Dynamics procurement specification 16ZK023D (which contains design and test requirements for all types of F-16 DTAs, including TLX lines) has been averaged into the unit cost of each type line. Some reasons for the lower cost of TLX lines are:

   (1) The greater producibility of TLX cord

   (2) The simplicity of the TLX tipless end fittings

   (3) The avoidance of costly materials in the TLX cord (e.g., there is no silver as is used in SMDC lines)

   (4) The continuous inspection of the plastic tubing during its manufacture (reference Section 3.0). Because of this continuous inspection there is no need for radiographic inspection of the cord. Radiographic inspection can be reserved for use only for inspecting the connections of the cord to its end fittings.

Table I Price of Various Types of F-16 DTAs Relative to Price of TLX Lines

Type of DTA	Price Ratio
ST (TLX)	1.00
S (standard)* (see Figure 11)	1.27
FC (flexible confined) (conventional FCDC with fiberglass and nomex overbraid)	4.57
FC (flexible confined) (small-diameter FCDC with wire overbraid)	5.52
C (confined) (conventional SMDC)	2.63

*Provided straight to General Dynamics. Subsequent forming by General Dynamics increases cost by approximately 20 percent.

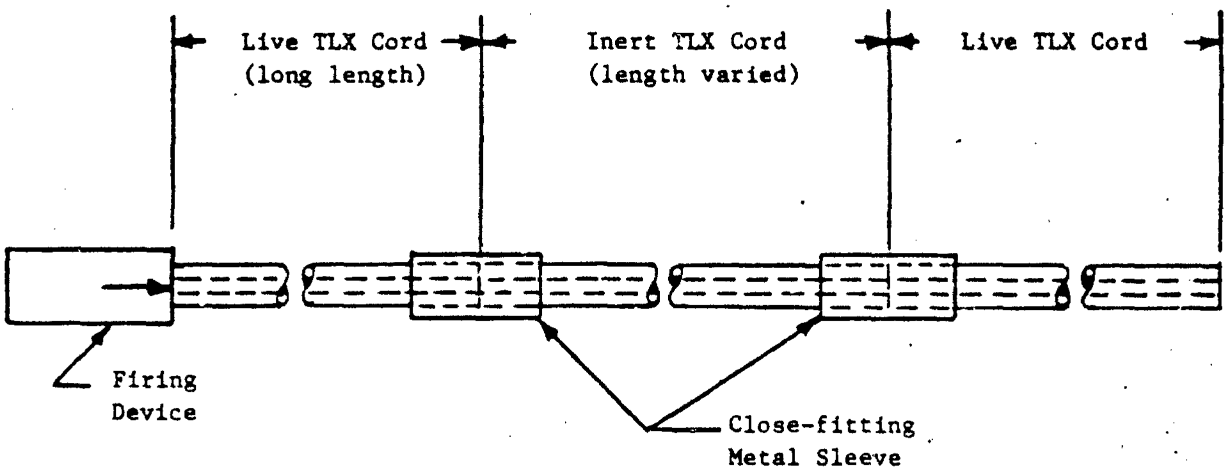
c. High Reliability. Tests have shown that the shock wave that moves along the cord will successfully cross large gaps (Figure 26), whereas in conventional metal-sheathed detonating cords very small gaps (e.g., 0.03-inch) will usually terminate detonation. The process by which TLX cord is manufactured (see Section 2.2) provides for positive determination that there is a continuous deposit of the reactive material in the TLX cord, whereas there is always a small possibility of a neck-down in the core of conventional, small-core-load, metal-sheathed detonating cord.

d. Small Quantity of Explosive. The nominal content of reactive materials (HMX explosive and aluminum powder) is 20 milligrams per meter of cord length, whereas the nominal content of explosive in standard 2.5-grain-per-foot SMDC and FCDC lines is 531 milligrams per meter. This very low explosive content (1 pound of reactive material is sufficient to make 14 miles of TLX cord) and the fact that the cord does not rupture when it is fired permits the user to handle and ship the cord as nonhazardous material. TLX assemblies with either tipless or standard ends will have transportation and storage classifications similar to those of SMDC and FCDC lines.

e. Small Size and Flexibility. The outside diameter of TLX lines is approximately 50 percent of the outside diameter of FCDC lines (Figure 27) and 82 percent of the outside diameter of SMDC lines. The length of the tipless end of TLX lines is substantially less than the length of the standard end of SMDC and FCDC lines. The minimum bend radius of TLX lines is much smaller than the minimum bend radius of SMDC and FCDC lines. These factors permit the use of TLX lines in places in which SMDC and FCDC lines cannot be accommodated.

f. Ruggedness. The plastic (Halar) of which the TLX cord is made is highly resistant to solvents, to ultraviolet radiation, and to the heat experienced during aircraft operation. The overbraided TLX cord will withstand much abuse without impairment of function (see Section 4.2). On the other hand, a small force will buckle the thin-wall housing of an SMDC line and thereby make it susceptible to fracturing when the line is detonated. The corrosion-resistant steel wire that overbraids TLX lines is very resistant to being broken or cut, whereas the textile overbraiding on the typical FCDC line is easily cut or broken. Consequently, TLX lines can be expected to successfully endure rougher service than can SMDC and FCDC lines.

g. <u>Great Flexibility</u>. Because TLX lines do not contain metal-sheathed cord, their flexibility is virtually unlimited (see Section 3.2).



Live TLX cord is plastic tubing whose inner surface is coated with reactive material (particles of aluminum and HMX).

Inert TLX cord is plastic tubing without coating of reactive material.

Test Procedure

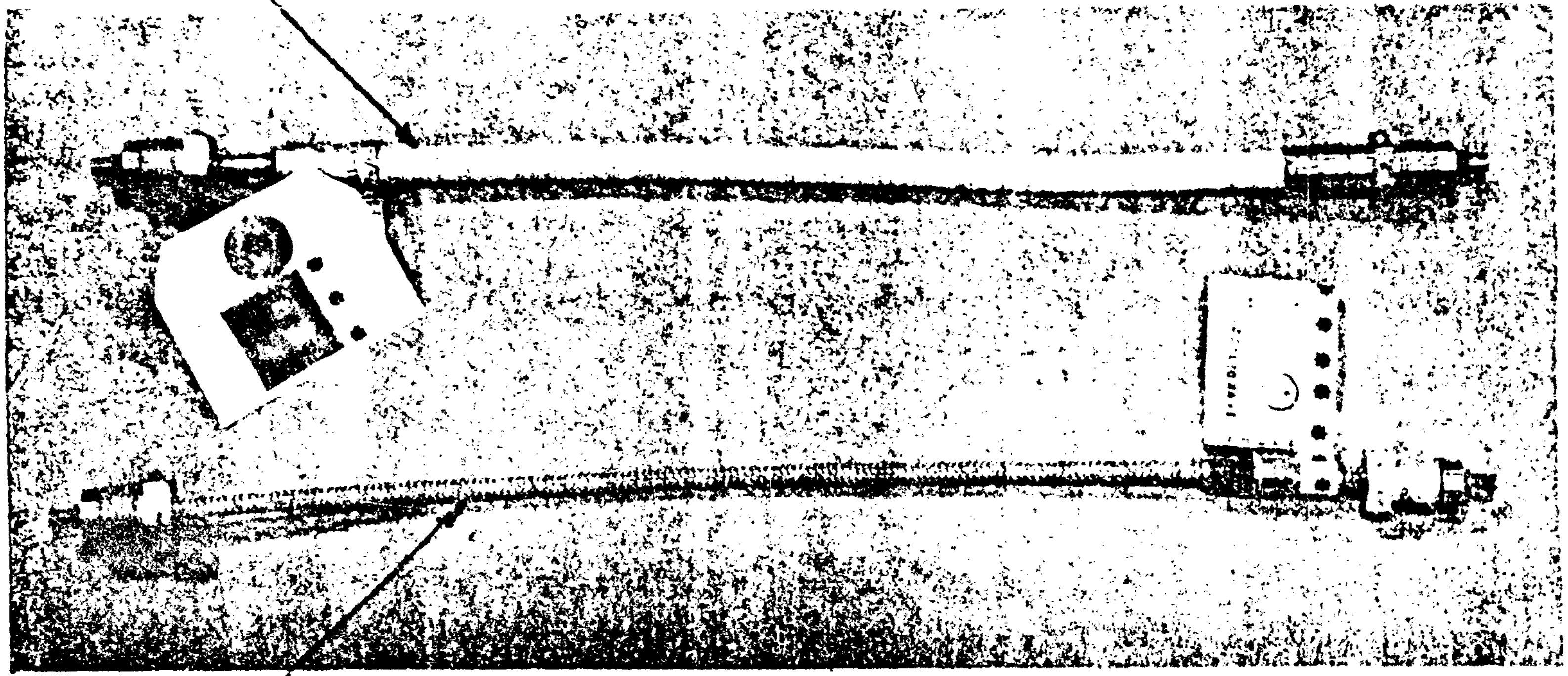
A group of specimens as shown above having differing length sections of inert cord were initiated at ambient temperature. Those specimens in which both of the live sections of TLX cord fired were termed successful. Those specimens in which the length of live TLX cord downstream of the inert cord was not initiated was termed unsuccessful. The test results were analyzed statistically to obtain the values listed below.

Test Results

No-fire gap:	18.74 inches
50%-fire gap:	11.88 inches
All-fire gap:	7.55 inches

Figure 26 Results of TLX Gap Tests

Type F (flexible) DTA formerly used to interconnect the F-16A Canopy with the fuselage



Type ST DTA (TLX line) with standard ends now used to interconnect the F-16A canopy with the fuselage

Figure 27 Comparison of Type F DTA and Type ST DTA (TLX line)

APPENDIX A

This appendix contains descriptions of the procedures and results of the vibration and shock tests performed during the formal qualification tests of the TLX lines.

1.0 VIBRATION TEST

1.1 Procedure

The 18 TLX lines in Test Groups III, IV, and V (Figure 17) were first divided into equal quantities for vibration testing at -65°F, ambient, and 200°F. Those lines in Group III had previously been exposed to temperature cycling (with humidity). The lines, mounted as shown in Figure A-1, were subjected to the test levels specified in Figure A-2 sequentially along each of the three orthogonal axes of the test fixture. The excitation was accomplished in two parts:

a. A sinusoidal cycling imposed over a background random spectrum as illustrated in Figure A-2. The test time for the combined sine sweep and random excitation was one hour per axis. The logarithmic sweep rate was such that approximately 7.6 minutes were required to complete each double sweep.

b. Upon completion of the combined sine and random exposure, the same lines were subjected to a sinusoidal resonance search and subsequent dwells. Since no resonances were observed in any axes, the five-minute dwells were performed at the center frequency of the first four harmonics of the gunfire frequency and at two additional higher frequencies. The dwell frequencies and levels, which were the same in each axis, are tabulated below.

Frequency (Hz)	Level (G)
100	22
200	22
300	22
400	22
600	16.5
1,000	16.5

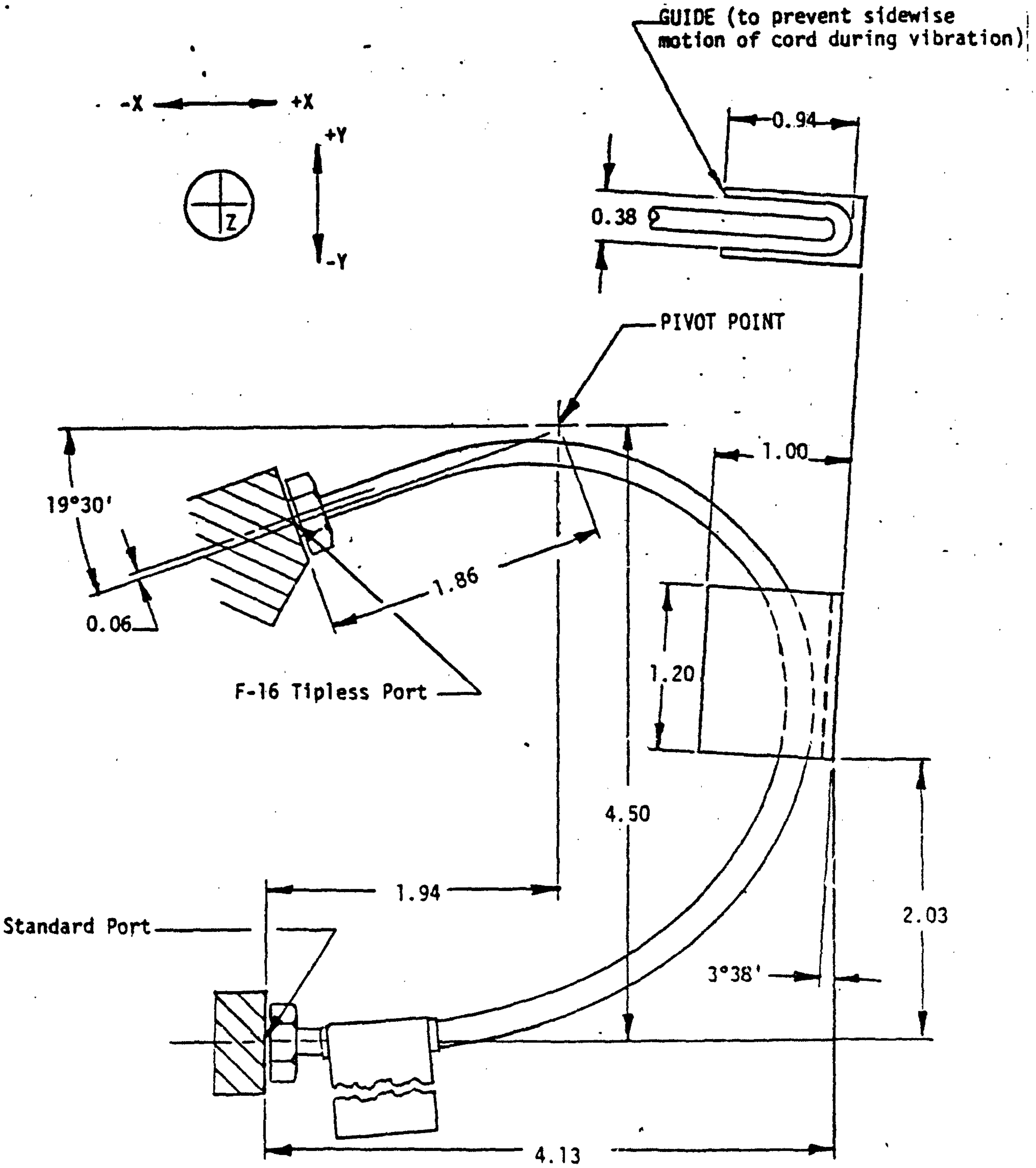


Figure A-1 Arrangement for Vibration and Shock Tests of TLX Line

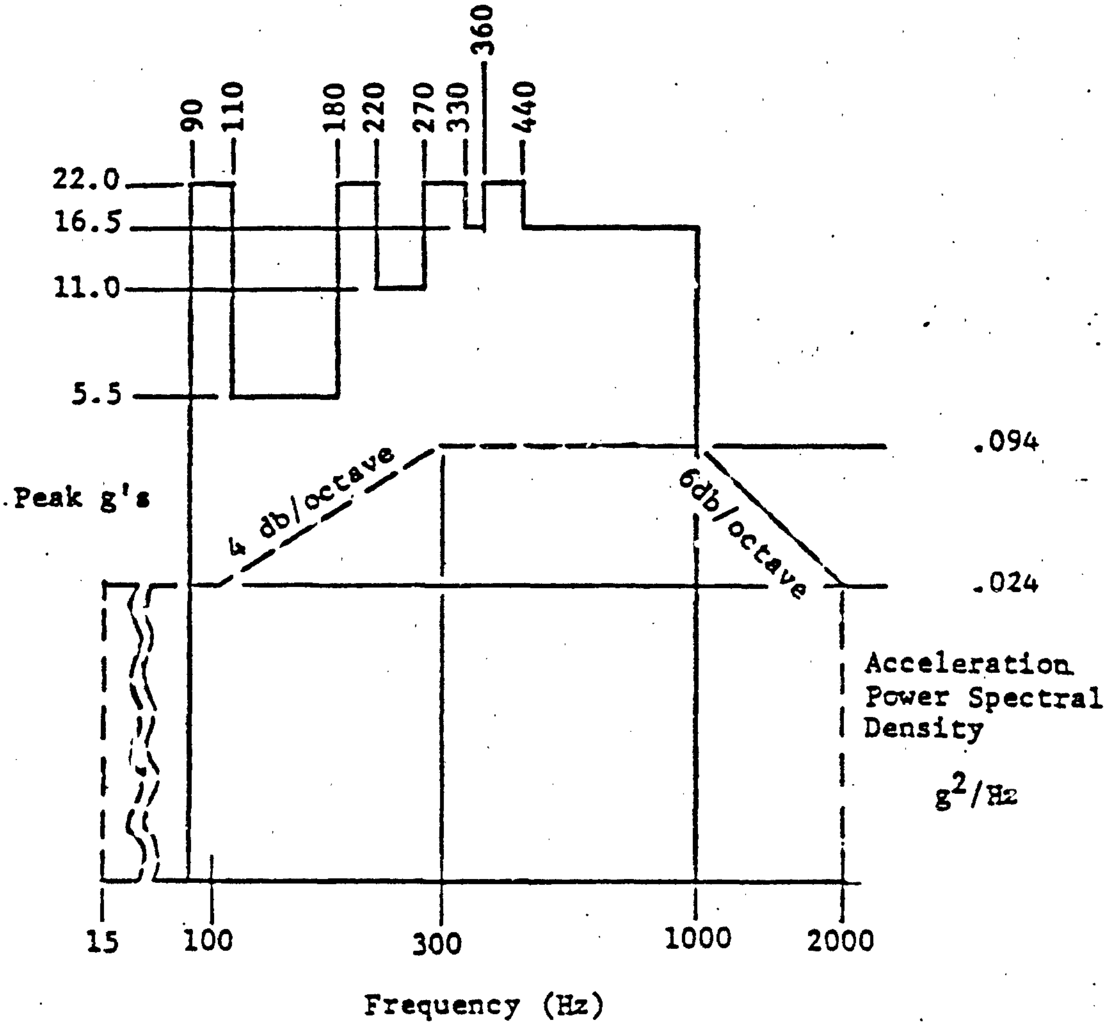


Figure A-2 Envelopes for Vibration Testing of TLX Lines

After vibration was completed, the lines were removed from the fixture and visually examined for indications of damage.

1.2 Results

None of the lines detonated during any of the vibration exposures. There was no evidence of damage to any of the lines subjected to vibration. The lines of Group V were subsequently subjected to temperature cycling, then functioned. All lines propagaged completely when functioned after these tests.

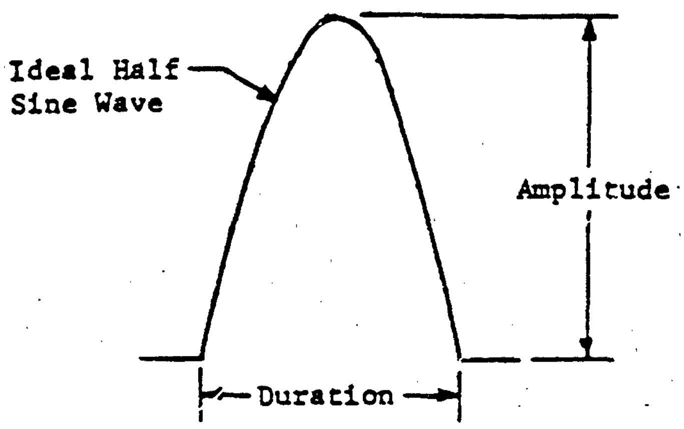
2.0 SHOCK TEST

2.1 Procedure

The six lines in Test Group VI (Figure 17) were mounted in the configuration shown in Figure A-1. They were then subjected to the shock pulses illustrated in Figure A-3 in each direction along each of the three mutually perpendicular axes. After the shock testing in the X-axis was completed, the six lines were removed from the fixture for reorientation and fixture checkout in the Y-axis. When the lines were reinstalled, they were all positioned in the wrong ports, i.e., the tipless ends were placed in the standard ports, and the standard ends in the tipless ports. This was again done for the Z-axis tests. The lines were reinstalled correctly and the Y-axis test repeated. The Z-axis test was not repeated, since the direction of the shock was perpendicular to the plane of the lines, and therefore would not effect the results.

2.2 Results

None of the lines fired during the shock test. There was no evidence of damage to any of the lines. All six lines propagated completely when functioned.



Axis	Peak Amplitude g's	Nominal Duration Milliseconds
Longitudinal	40	11
Vertical	20	11
Lateral	15	11

Each specimen was subjected to six shock pulses, one in each direction (plus and minus) along each of three mutually perpendicular axes (see Figure A-1), at the amplitudes listed above. Two of the specimens were tested while at 200°F, two while at -65°F, and two at room temperature.

Figure A-3 Requirements for Shock Tests of TLX Lines

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PYROTECHNICS AND EXPLOSIVES APPLICATIONS SECTION
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27, 28 and 29 September 1983

GENERAL DYNAMICS
Ft. Worth, Texas

TITLE A New Ejection Seat Sequenced with TLX®

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ABSTRACT

A new ejection seat is under development for use in high-performance military aircraft. Event sequencing on ejection seats throughout the world has up to now used, for the most part, the old, heavy hot-gas systems first developed 30 to 40 years ago. The new seat is being developed by Stencel Aero Engineering Company who chose to utilize TLX® to perform those functions formerly done with hot gas. The results are a lighter weight, less costly system having greater simplicity (read reliability) and adaptability. When a TLX® interseat sequencing system for multiple seat aircraft is coupled with this new seat, even greater cost and weight savings can be made.

THE MATHEMATICAL FOUNDATION
FOR THE "RIDGE-CUT" TECHNIQUE
USED IN EXPLOSIVE BOLTS

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For years experiments have shown that the optimum Ridge-Cut angle used in Explosive Bolts is approximately 120°. This paper gives a rational foundation for this angle by giving the exact solution to the equations of classical elastodynamics applied to a longitudinal shock wave impinging on an infinite wedge. Numerical results are given for the optimum angle as a function of v/c, where v is longitudinal velocity of sound in the elastic medium and c is the detonation velocity of the explosive used to fracture the bolt.

1. INTRODUCTION

An empirical design, the so-called "Ridge-Cut" technique, was developed over 20 years ago (see Ref. [1]) for explosive bolts which produce minimal shrapnel, little swelling and a "clean" break. The mathematical foundation for the Ridge-Cut design has remained elusive.

Figure 1 shows a 2-inch diameter fired Ridge-Cut bolt, and Figure 2 shows the basic design. For most conventional explosives (e.g., RDX) and bolt materials (e.g., high-strength steels), it has been experimentally determined over many years that the Ridge-Cut angle should be about 120° to give a clean break with minimal shrapnel and swelling. Considering the small degree of permanent deformation which occurs in a well designed explosive bolt, we use the equations of classical elastodynamics (which properly apply only to deformation in the elastic range) to show that a Ridge-Cut angle of about 120° follows from the exact solution of a plane shock wave impinging on a corner (infinite wedge).

The mathematical foundation for other Ridge-Cut parameters (e.g., charge weight, charge cavity dimensions, etc.) will be given in a future paper.

2. REVIEW OF CLASSICAL ELASTODYNAMICS

2.1 General

Consider a singular surface of order 1 (see Ref. [2], Chapter C, for a discussion of singular surfaces), i.e., a surface (a shock wave) across which the displacement vector is continuous but its first derivatives are not*. Only two kinds of shock waves are possible:

Longitudinal Shocks

$$[t^i{}_j] = A\,[\,\delta^i{}_j + (\nu^{-1} - 2)\, n^i n_j] \qquad (1)$$

$$\text{Wave Speed} = v = \sqrt{\frac{E}{\rho\,(1+\nu)} \cdot \left(\frac{1-\nu}{1-2\nu}\right)} \qquad (2)$$

Transverse Shocks

$$[t^i{}_j] = C\,(\lambda^i n_j + \lambda_j n^i) \qquad (3)$$

$$\text{Wave Speed} = v_t = \sqrt{\frac{E}{2\rho(1+\nu)}} = v\sqrt{\frac{1-2\nu}{2-2\nu}} \qquad (4)$$

where

$t^i{}_j$ = stress tensor

$[t^i{}_j] = t^i{}_j|_+ - t^i{}_j|_-$ = jump of $t^i{}_j$ across the shock

n^i = normal to the shock wave

λ^i = vector perpendicular to n^i

E, ν, ρ = Young's Modulus, Poisson's Ratio, density of elastic medium respectively

A, C = to be determined

The notation throughout follows that in Ref. [2], [3], [4] and [5] (equations (1) - (4) are given in [5], Chapter 6).

---

*The major results in this paper can be shown to be valid for singular surfaces of order n = 1, 2, 3, ...

2.2 Application to a Longitudinal Shock Impinging Obliquely on a Half Space

Consider a longitudinal shock with normal n^i obliquely incident on an elastic half space, as shown in Figure 3. Let the medium in front of this shock be stress-free, and let the stress tensor behind the shock be constant (a posteriori we shall show this is possible). Let N^i and M^i respectively be the normals to the reflected longitudinal and transverse waves. From (1) - (4) we have

$$t^i{}_j = \begin{cases} -A\,[\delta^i{}_j + (\nu^{-1} - 2)\,n^i n_j] \quad \text{in region } R_2 \\ -A\,[\delta^i{}_j + (\nu^{-1} - 2)\,n^i n_j - B\,[\delta^i{}_j + (\nu^{-1} - 2)\,N^i N_j] \\ \quad \text{in region } R_3 \\ -A\,[\delta^i{}_j - (\nu^{-1} - 2)\,n^i n_j - B\,[\delta^i{}_j + (\nu^{-1} - 2)\,N^i N_j] \\ \quad - C\,[\lambda^i M_j + \lambda_j M^i] \quad \text{in region } R_4 \end{cases} \tag{5}$$

where A, B and C are constants.

In region R_2, the principal stresses are (from (5))

$$\begin{aligned} t_1 &= -(\nu^{-1} - 1)\,A \equiv t_{max}, \text{ corresponding to the eigenvector } n^i \\ t_2 &= -A, \text{ corresponding to the eigenvector perpendicular to } n^i \\ &\qquad \text{and in the plane of Figure 3} \\ t_3 &= -A, \text{ corresponding to the eigenvector perpendicular to} \\ &\qquad \text{the plane of Figure 3} \end{aligned} \tag{6}$$

Thus A is a measure of the strength of the shock; we take A positive (corresponding to a compressive stress). Using the boundary condition $t_{xy} = t_{yy} = t_{yz} = 0$ at the half space edge, we calculate:

$$\frac{B}{A} = \gamma(\alpha), \; \frac{C}{A} = (\nu^{-1} - 1)\cot 2\beta\,[\gamma(\alpha) + 1] \tag{7}$$

where

$$\gamma(\alpha) \equiv -1 + \frac{2}{1 + \left(\frac{2-2\nu}{1-2\nu}\right) \frac{\cos 2\beta \cdot \cot 2\beta}{\sin 2\alpha}} \tag{8}$$

$$\sin\beta = \sin\alpha\sqrt{\frac{1-2\nu}{2-2\nu}} \tag{9}$$

From (5) and (7) we have in region R_3

$$t^i{}_j = -A\left\{[1 + \gamma(\alpha)]\,\delta^i{}_j + (\nu^{-1} - 2)\,n^i n_j + (\nu^{-1} - 2)\,\gamma(\alpha)\,N^i N_j\right\} \tag{10}$$

Notice that with (7), (5) satisfies the differential equations ($t^i{}_{j;i} = \rho\ddot{u}_j$), the boundary conditions and jump conditions.

3. APPLICATION TO A LONGITUDINAL SHOCK IMPINGING ON A CORNER (INFINITE WEDGE)

Consider the problem in Section 2.2, except now the longitudinal shock with normal n^i is incident on the corner in Figure 4A and Figure 4B. From (10) we have

$$t^i{}_j = \begin{cases} -A\left\{(1 + \gamma_1)\,\delta^i{}_j + (\nu^{-1} - 2)\,n^i n_j + \gamma_1(\nu^{-1} - 2)\,N^i_{(1)}N_{(1)j}\right\} & \text{in region } S_1 \\ -A\left\{(1 + \gamma_2)\,\delta^i{}_j + (\nu^{-1} - 2)\,n^i n_j + \gamma_2(\nu^{-1} - 2)\,N^i_{(2)}N_{(2)j}\right\} & \text{in region } S_2 \end{cases} \tag{11}$$

where $\gamma_1 \equiv \gamma(\alpha_1)$, $\gamma_2 \equiv \gamma(\alpha_2)$ and $\gamma(\alpha)$ is given by (8). Let region S be the region immediately behind the shock intersection in in Figure 4B. Using (11) and applying the jump condition (1) across both reflected longitudinal shocks, one finds

$$t^i{}_j = -A\left\{(1 + \gamma_1 + \gamma_2)\,\delta^i{}_j + (\nu^{-1} - 2)\cdot(n^i n_j + \gamma_1 N^i_{(1)}N_{(1)j} + \gamma_2 N^i_{(2)}N_{(2)j})\right\} \quad \text{in region } S \tag{12}$$

Notice that the stress in S, equation (12), is not simply the sum of the stresses in S_1, S_2 and S_3.

The principal stresses in S follow from (12):

$$t_1(\theta, \alpha_1, \nu) = \frac{1 + \gamma_1 + \gamma_2 + Q}{2 - 2\nu} t_{max} \tag{13}$$

$$t_2(\theta, \alpha_1, \nu) = \frac{1 + \gamma_1 + \gamma_2 - Q}{2 - 2\nu} t_{max} \tag{14}$$

$$t_3(\theta, \alpha_1, \nu) = \frac{\nu}{1-\nu} (1 + \gamma_1 + \gamma_2) t_{max} \tag{15}$$

where

$$Q \equiv (1 - 2\nu) \left\{ 1 + (\gamma_1)^2 + (\gamma_2)^2 + 2\gamma_1 \cos 4\alpha_1 + 2\gamma_2 \cos 4\alpha_2 + 2\gamma_1\gamma_2 \cos 4\theta \right\}^{\frac{1}{2}} \tag{16}$$

and $t_{max} \equiv -(\nu^{-1} - 1) A$ is the largest principal stress in region S_3 (see equation (6)). If the explosive in Figure 2 is initiated at x = o with velocity c, say the detonation speed of the explosive, then for the planar geometry in Figure 4 we may write

$$\sin \alpha_1 = \frac{v}{c} \tag{17}$$

Figures 5, 6 and 7 show the principal stresses (13), (14) and (15) as a function of Ridge-Cut angle θ, for $\nu = .28$ and some values of v/c. Figure 6 is noteworthy: the principal stress t_2 in S is tensile, i.e., when the two reflecting longitudinal fronts interact at a point, the principal stress t_2 changes instantly from compressive to tensile. One can show that the eigenvector corresponding to t_2 lies in the plane of Figure 4A and is approximately normal to n^1; thus the tensile force is tending to pull the bolt apart along the break section shown in Figure 2. Thus we seek that Ridge-Cut angle θ for which t_2 is the most tensile; the result, shown in Figure 8, follows from Figure 6 (equation (14)). For the range of v/c shown (which covers most commonly used explosives in a steel bolt), we see the optimum Ridge-Cut angle is between 95° and 125°; for RDX in steel (v/c = .62), θ = 117°.

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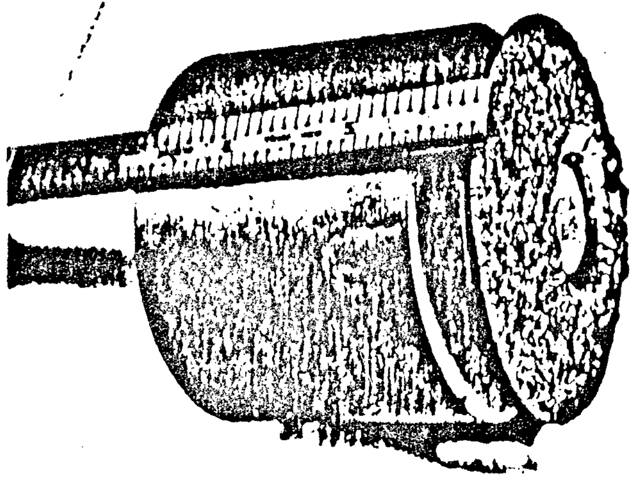

FIGURE 1: EXPLOSIVE BOLT, 2 IN. DIA.,
FIRED BY RIDGE-CUT TECHNIQUE

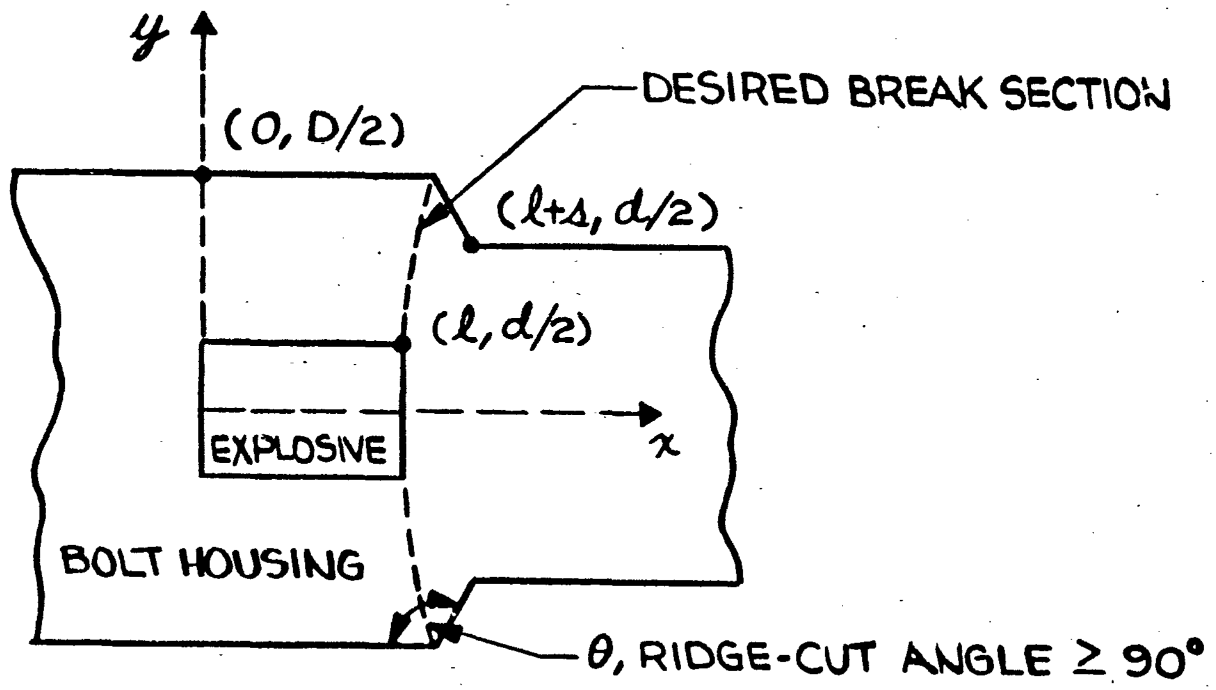

FIGURE 2: BASIC RIDGE-CUT DESIGN FOR EXPLOSIVE BOLT

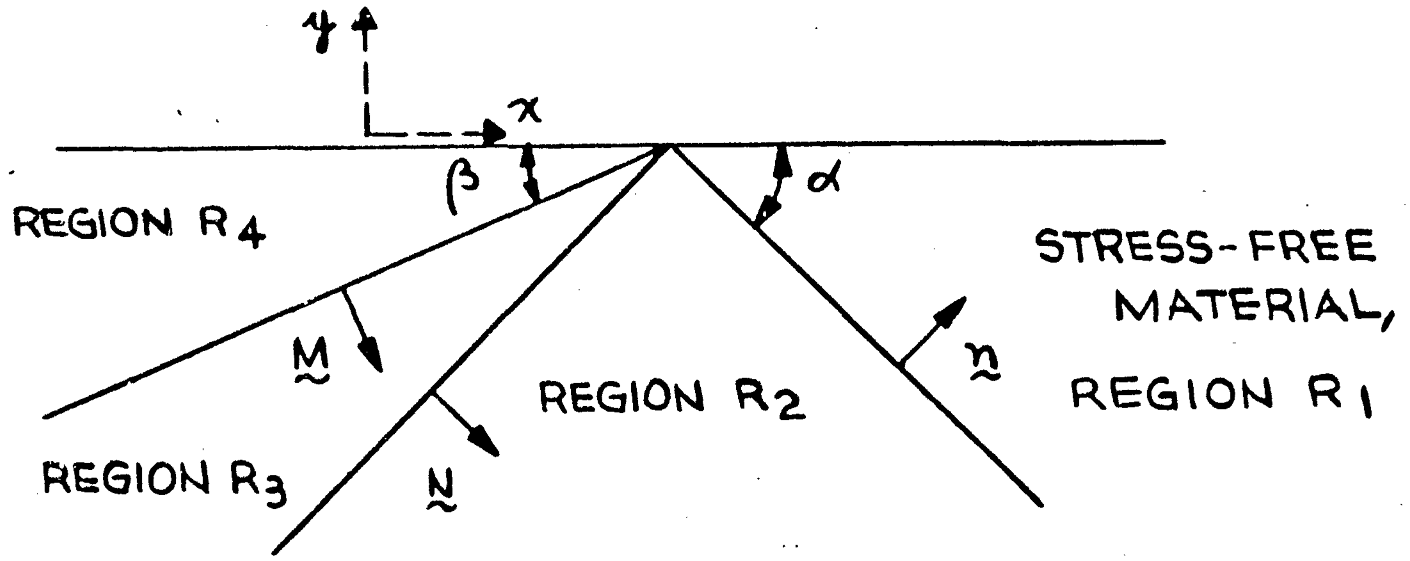

FIGURE 3: SHOCK OBLIQUELY INCIDENT ON HALF SPACE

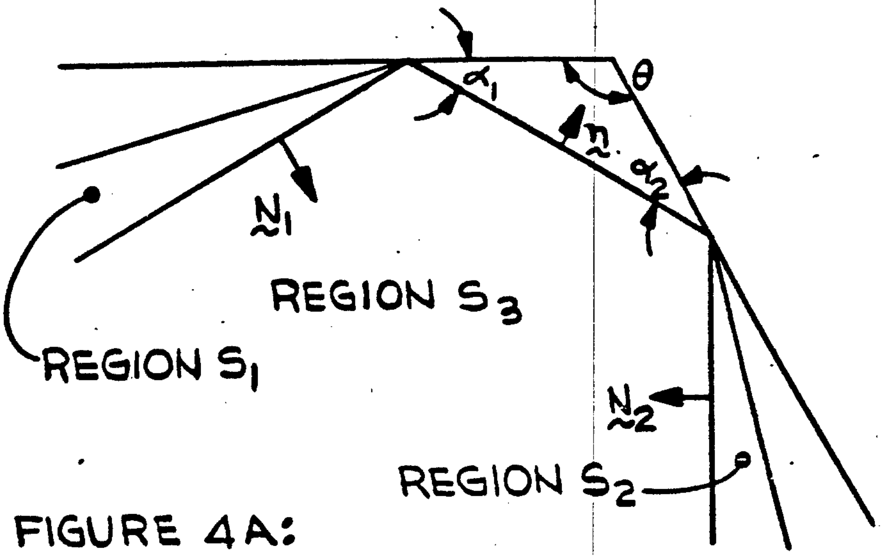

FIGURE 4A:
SHOCK INCIDENT ON CORNER

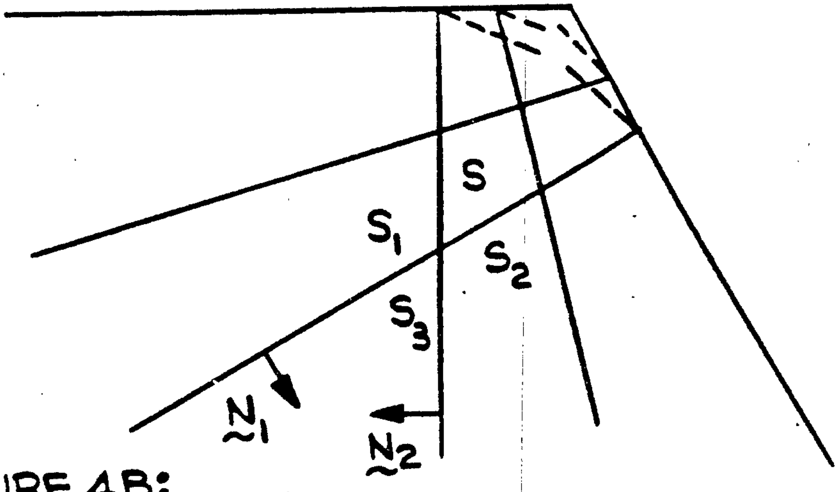

FIGURE 4B:
SHOCK REFLECTING FROM CORNER

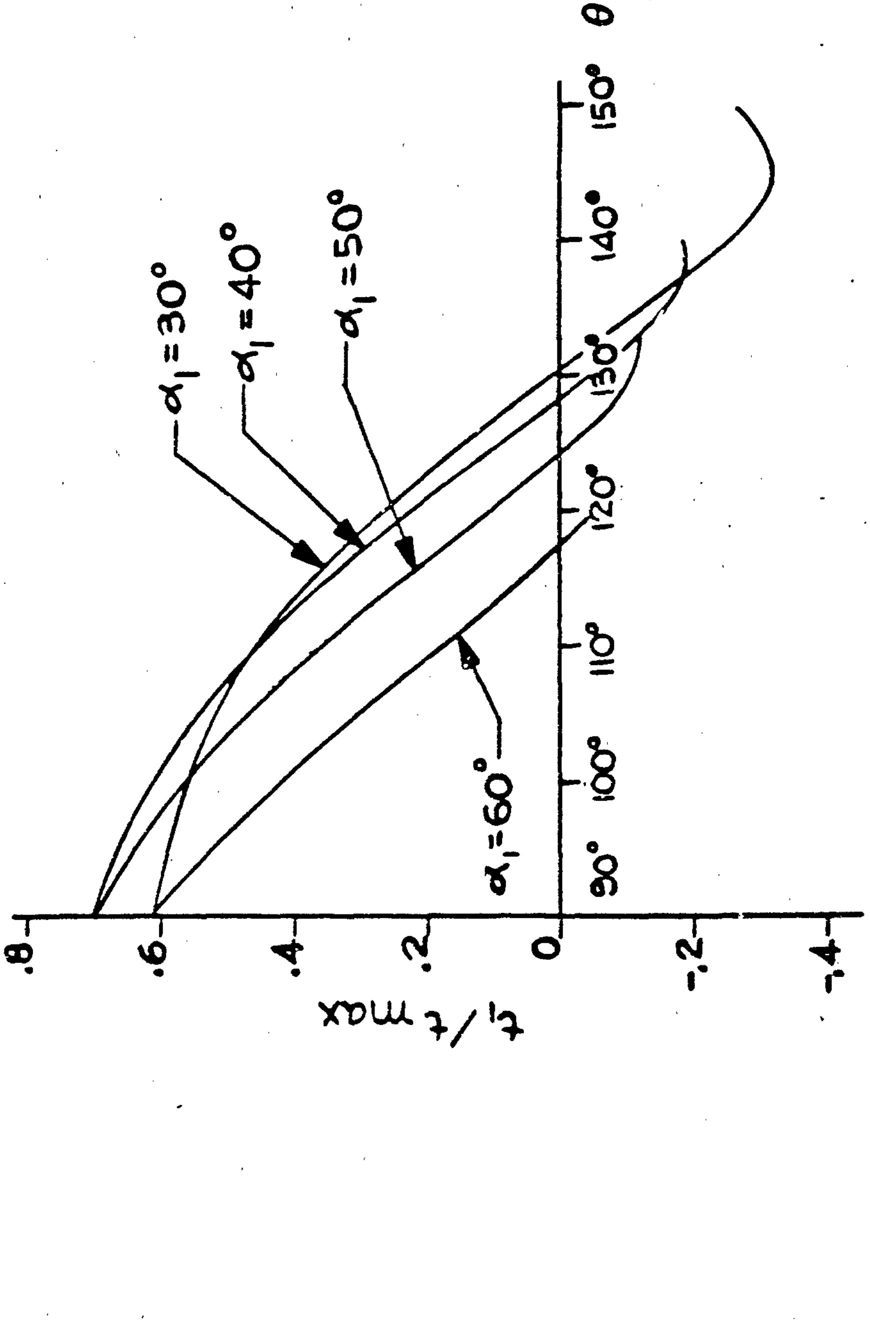

FIGURE 5: t_1/t_{max} VS. θ

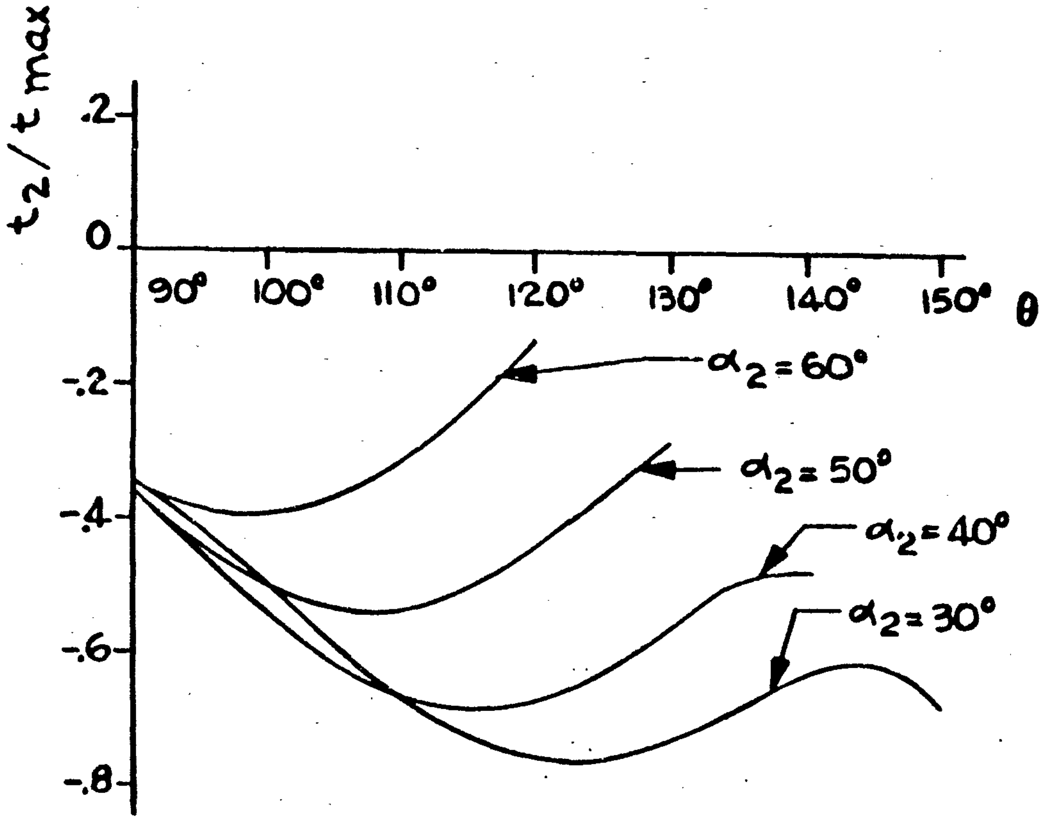

FIGURE 6: t_2/t_{max} VS. θ

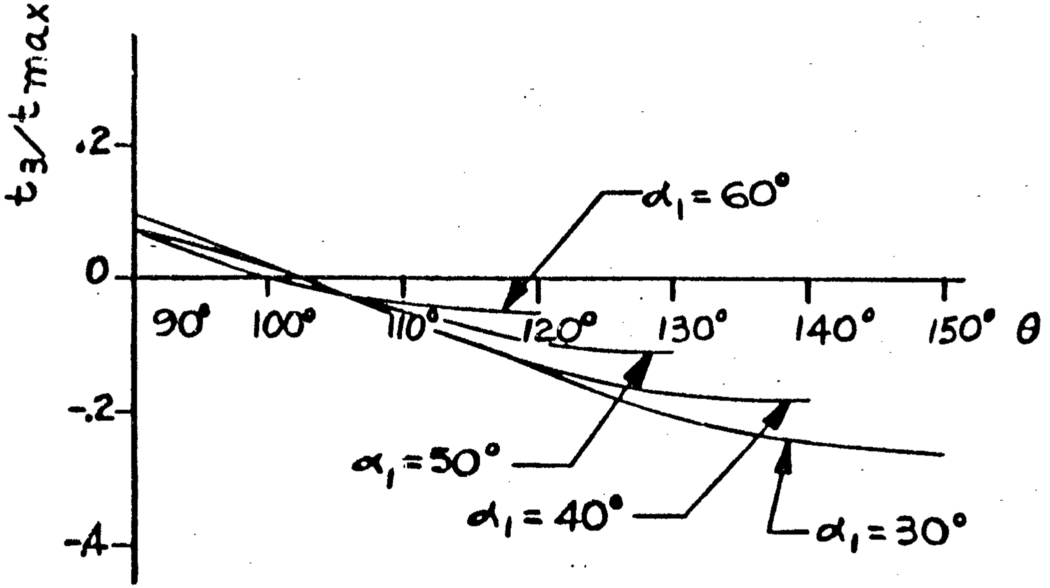

FIGURE 7: t_3/t_{max} VS. θ

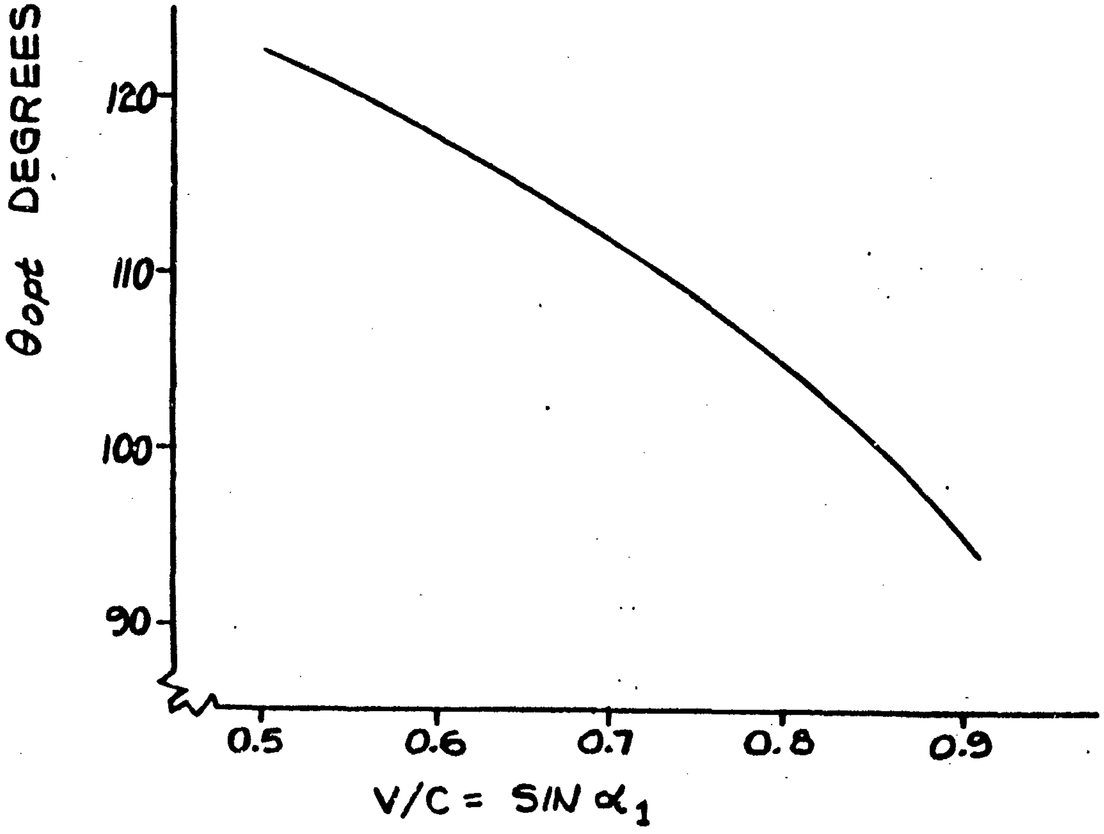

FIGURE 8: OPTIMUM RIDGE-CUT ANGLE VS. V/C

LA-UR - 83-2721

TITLE: NONPRIMARY-EXPLOSIVE, HOT-WIRE DETONATOR

AUTHOR(S): ROBERT H. DINEGAR

SUBMITTED TO: AMERICAN DEFENSE PREPAREDNESS ASSOCIATION
PYROTECHNICS AND EXPLOSIVES APPLICATIONS
SECTION ANNUAL FALL MEETING

GENERAL DYNAMICS
FORT WORTH, TEXAS

Los Alamos Los Alamos National Laboratory
Los Alamos, New Mexico 87545

FORM NO 836 R4
ST NO 2629 5/81

NONPRIMARY-EXPLOSIVE, HOT-WIRE DETONATOR

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A nonprimary-explosive, hot-wire detonator, employing the deflagration-to-detonation transition (DDT) process, has been developed. Pentaerythritol tetranitrate (PETN) is the explosive used. The assembly is nominally a 1-A/1-W/1-Ω system. The DDT process has been examined over a range of PETN specific surface values (3,000 - 14,500 cm^2/g) and pressing densities (1.0 - 1.4 g/cm^3). The reaction is sensitive to the degree of subdivision and the compactness of the explosive in which the transition takes place. It apparently happens better with PETN of small specific surface loaded at low density. Consistent transitions from burning to detonation occur in PETN pressings 9 mm or more in length, with diameters of about 2 mm. Increasing the charge diameter by a factor of 2 appears to allow a shortening of the required charge length by several millimeters.

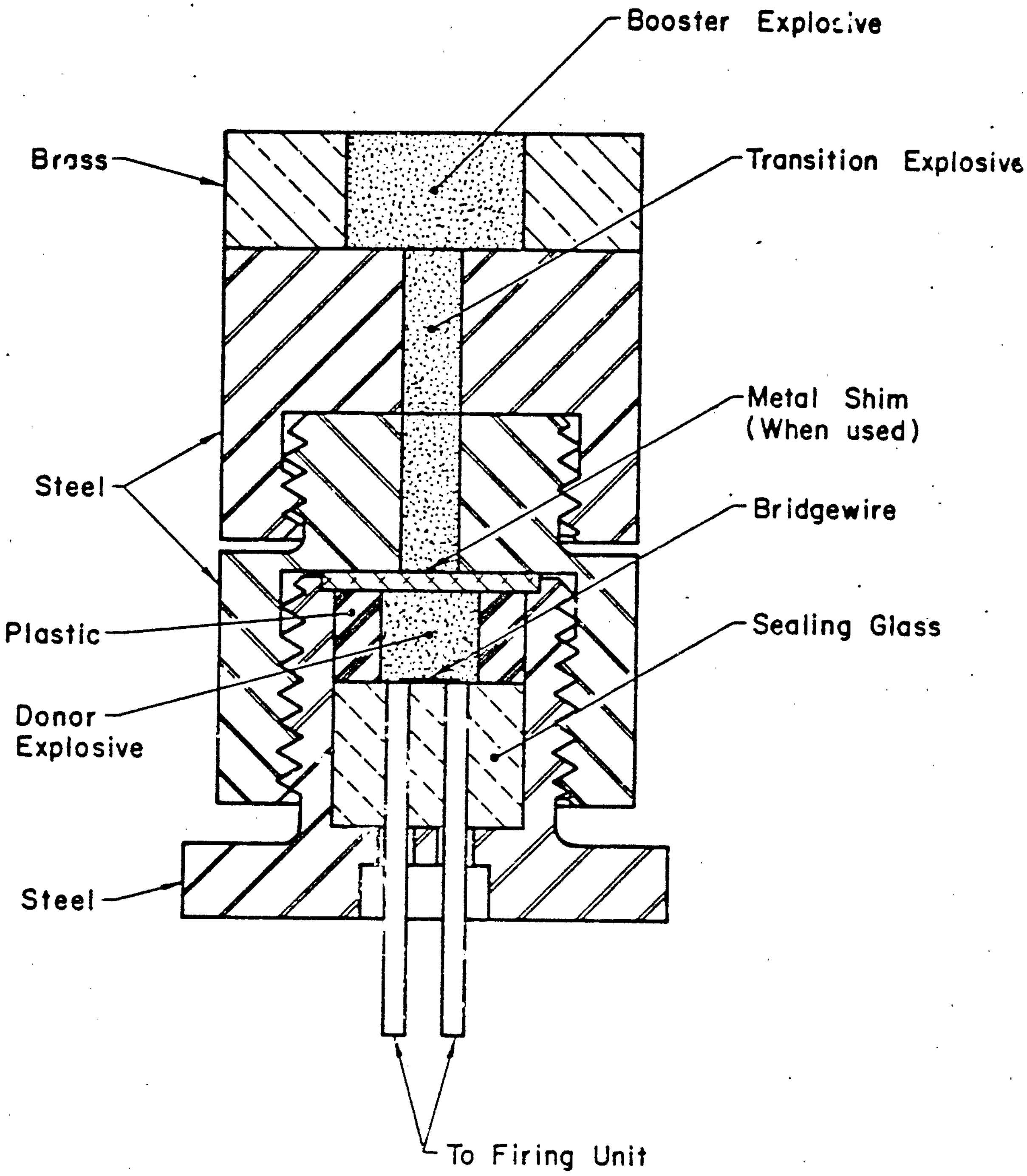
INTRODUCTION

Secondary explosives such as PETN can be ignited by a hot wire at low current and low voltage. If the confinement of the ignited explosive is restrictive enough and other criteria are met, the deflagration will build up (transit) into a detonation. This paper discusses developmental experiments leading to a functional explosive device and selected parameter studies on a hot-wire detonator (ER-345).

DDT DEVELOPMENTAL STUDIES

ER-322 donor assemblies (Fig. 1) with Nichrome V bridgewires of diameter 0.05 mm and a length 2.5 mm (room-temperature resistance of about 1 Ω), loaded to a density of 1.6 g/cm^3 with PETN of specific surface (S) 3650 cm^2/g, were found to have an ignition-current threshold value of about 1 A over an environmental temperature range of -54°C to +74°C. All-fire voltage and current values at the low temperature are 2.5 V and 1.4 A. They are 2.0 V and 1 A at the high temperature. The all-fail current value at +74°C is close to 0.7 A. While these values vary slightly over this temperature range, it appears that this assembly is a nominal 1-A/1-W/1-Ω system.

An indication of the reproducibility in performance of this donor portion (ER-322) of the hot-wire DDT assembly is given in Table I. These data come from experiments using HMX instead of PETN as the donor explosive charge, but should be representative of PETN as well. The last column gives the value of the function time (t_f)--the time from start



DDT ASSEMBLY (ER-322 Type)

Fig. 1

TABLE I

Reproducibility of Experimental Results

Bridge Diam (mm)	Bridge Length (mm)	HMX Loading Density (g/cm^3)	Function Current (A)	Function Time (ms)
0.051	1.7	1.64	2.18	3.06
			2.18	2.99
0.051	1.7	1.64	1.41	9.54
			1.39	10.18
0.051	3.1	1.64	2.77	1.92
			2.73	1.96
0.051	4.5	1.64	1.64	7.04
			1.60	7.79
0.038	1.55	1.64	0.87	12.32
			0.87	10.72
0.038	1.55	1.64	1.17	4.29
			1.17	4.11
0.038	1.55	1.64	2.43	1.19
			2.20	1.18
0.079	1.62	1.64	4.60	3.12
			4.68	3.28
0.051	1.7	1.56	3.15	1.27
			3.10	1.27
0.051	1.7	1.56	1.49	7.77
			1.47	8.07
0.038	1.55	1.56	1.35	3.22
			1.35	3.22
0.079	1.55	1.56	6.74	3.65
			6.74	2.94

of electric current through the bridgewire until the explosive material ignites and the resulting burning reaches a self-sustaining reaction--over a range of bridgewire dimensions at two explosive loading densities. The current value when this functioning occurs is called the function current, I_f, and is shown in the fourth column. For a given value of I_f, t_f appears to vary by several percent.

The transition barrel portion of the hot-wire explosive device was made in two sections, loaded separately and then screwed together to form the cylindrical transition cavity. Each section of the transition barrel has a 2.5-mm-inner diameter and 7.0-mm length, giving an overall 14-mm length. These barrels were loaded with PETN of three widely differing specific surface values (S = 3650, 8400, and 14,600 cm^2/g) at 1.0-g/cm^3 loading density. The DDT reaction took place in each. Dents were produced in 6061-T6 aluminum witness slugs attached to the downstream end of the transition barrels. No consistent variation in dent depth with PETN specific surface change could be found. It appears, however, that the PETN with the smallest S value (largest "average particle size") produced the deepest dent in the witness slug. The density of the PETN sample in the transition zone was also varied at constant powder specific surface. Dents were again observed in the aluminum witness slugs, showing that the DDT reaction had occurred. Table II gives both sets of data.

TABLE II

DDT in All-PETN ER-322 Assemblies Without a Booster Pellet

Donor: PETN $S = 3650\ cm^2/g$ Density = $1.64\ g/cm^3$ Mass = 100 mg

	Transition Barrel				6061-T6 Aluminum Witness Block Dent
PETN S (cm^2/g)	Mass (mg)	Density (g/cm^3)	Diameter (mm)	Length (mm)	Depth (mm)
3650	72	1.0	2.5	14.0	0.7
8400	72	1.0	2.5	14.0	0.5
14600	72	1.0	2.5	14.0	0.5
3650	72	1.0	2.5	14.0	0.4
3650	86	1.2	2.5	14.0	0.8
3650	100	1.4	2.5	14.0	0.8

Booster pellets of PBX 9407 material (density = $1.6\ g/cm^3$) were substituted for the witness slugs to see whether the detonation produced in the DDT was strong enough to initiate a high-density, secondary-explosive pellet. All systems detonated. The transition-zone PETN that was examined had an S value of $3650\ cm^2/g$ and was pressed to 1.0-, 1.2-, and $1.4\text{-}g/cm^3$ density. In these experiments we measured the diameter and the depth of the dent in a 2024 Dural witness block and calculated the estimated cylindrical volume. The data from these shots are given in Table III.

Over 40 complete assemblies were fired at low, ambient, and elevated temperatures. Aluminum (6061-T6) confinement shims (0.8 mm thick) were used between the donor and transition charges to enhance pressure buildup in the donor and provide more efficient compression in the transition charge. The detonator, however, will function quite satisfactorily without the confinement plate. High-density PETN and PBX 9407 pellets were the booster charges. All shots produced dents in 2024 Dural witness blocks, as evidence of detonation. Expansion of the transition barrel diameters clearly show the buildup to detonation takes place in the transition charges of PETN and not in the booster pellets. The cylindrical volume of the dents produced in the witness plate depends upon the density of the booster pellet. The data are given in Table IV.

TABLE III

DDT in All-PETN ER-322 Assemblies With a Booster Pellet

Donor: PETN $S = 3650\ cm^2/g$ Density = $1.64\ g/cm^3$ Mass = 100 mg

Booster Pellet: PBX 9407 Density = $1.6\ g/cm^3$ Mass = 376 mg

	Transition Barrel				2024 Dural Witness Block Dent		
PETN S (cm^2/g)	Mass (mg)	Density (g/cm^3)	Diameter (mm)	Length (mm)	Depth (cm)	Diameter (cm)	Volume (cm^3)
3650	72	1.0	2.5	14.0	0.28	1.43	0.4
3650	86	1.2	2.5	14.0	0.23	1.41	0.4
3650	100	1.4	2.5	14.0	0.21	1.54	0.4

TABLE IV

Dent Characteristics as a Function of

Environmental Temperature

Dent				
Depth/Diam (mm)	Vol (cm^3)	Booster Material	Pellet Density (g/cm^3)	Environmental Temperature (°C)
2.1/10.2	0.2	PETN	1.3	-54
2.0/11.6	0.2	PETN	1.3	+20
2.3/10.6	0.2	PETN	1.3	+74
2.6/11.7	0.3	PETN	1.6	-54
2.4/13.8	0.4	PETN	1.6	+20
2.9/12.3	0.3	PETN	1.6	+74
2.6/12.6	0.3	PBX 9407	1.6	-54
2.5/13.0	0.3	PBX 9407	1.6	+20
2.9/12.5	0.3	PBX 9407	1.6	+74

NONPRIMARY-EXPLOSIVE (PETN), HOT-WIRE DETONATOR (ER-345)

The construction of the PETN-DDT, hot-wire detonator came about as a result of ad hoc testing. Once the approximate successful parameters had been defined, a prototype weapon detonator could be designed ab initio. The ER-345 (Fig. 2) is the result. The donor portion is the ER-322. The transition charge barrel is of a single piece of steel whose length and bore diameter can easily be modified. If the length/diameter ratio of this barrel is large, its loading generates a new detonator parameter, i.e., resultant explosive density gradients.

Detonators that had transition barrels 14 mm long with a 2.5-mm-bore diameter were assembled. These dimensions met the criteria of more than enough length for deflagration-to-detonation buildup and at the same time provided a large (ca. 5) length/diameter ratio. The barrels were loaded in one and two pressing operations. The results of firing detonators so assembled are shown in Table V. Pressing Mode A is a single loading of 80 mg of PETN, pressed from the donor end. This produces the highest transition-barrel density at the donor end and the lowest at the booster-pellet end. Mode B is a two-step (40 mg each) pressing operation from the donor end. This procedure still provides the lowest density at the booster-pellet end, but the density in the tube no longer increases smoothly to the donor end. It has a high/low density interface near the center of the barrel. Mode C gives the highest density at the booster-pellet end with a smooth decrease to the donor end. Mode D is similar to Mode B in that the density gradation from booster-pellet to donor end is no longer uniform. It differs in that Mode D has the highest resultant density at the booster-pellet end.

All detonators fired and gave dents in aluminum witness blocks. PBX 9407 booster pellets gave cylindrical dents of larger volume when they were initiated by the configurations with the highest density PETN at their end. We feel this is because of a faster and stronger buildup process in the transition barrel when the donor ignites lower-density PETN as well as the booster pellet being initiated closer to its

ER-345

ALL SECONDARY HOT WIRE DETONATOR

1A/1W NO FIRE 2.5A ALL FIRE

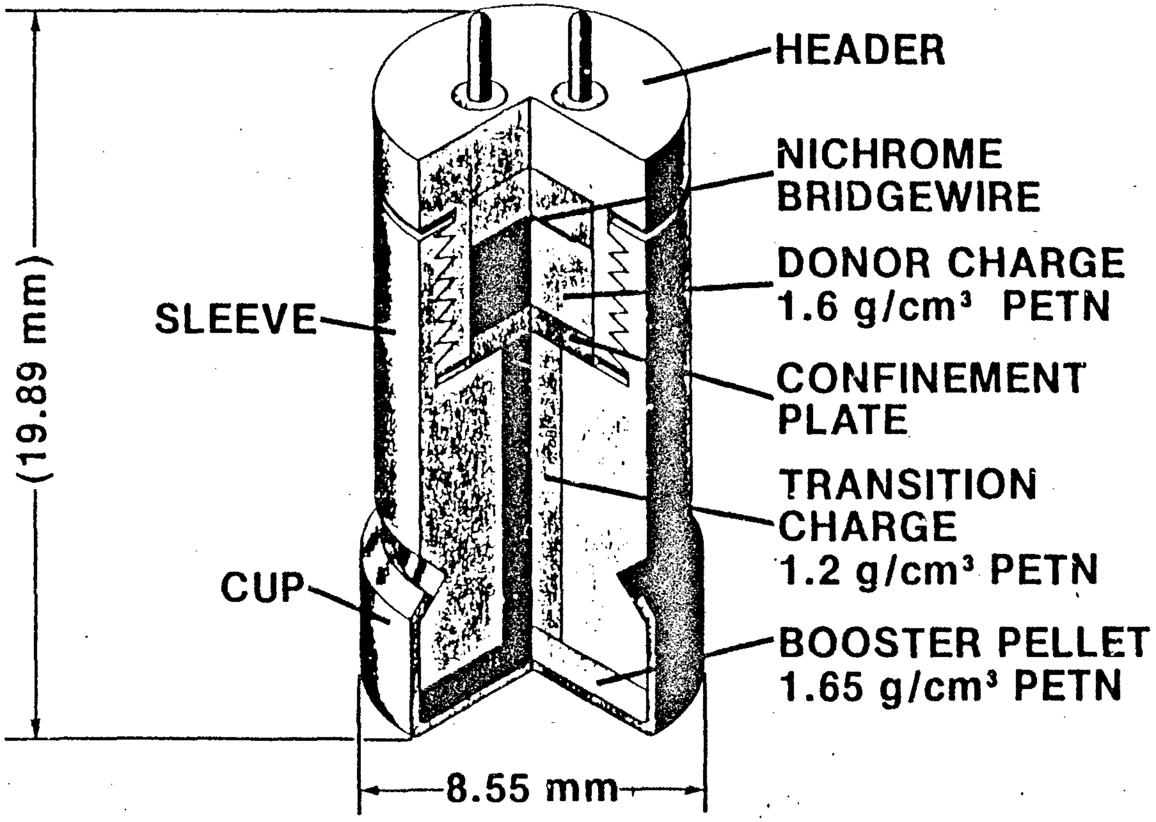


Fig. 2

TABLE V

Effect of PETN Transition-Zone Pressing Mode on

ER-345 Booster Pellet Dent Dimensions

Mode of Pressing	Dent Dimensions Diam/Depth (cm)		Vol (cm^3)
A	1.3	0.2	0.3
B	1.4	0.2	0.3
C	1.5	0.2	0.4
D	1.5	0.2	0.4

Pressing Mode A: One PETN pressing from donor end; 80 mg.
Pressing Mode B: Two separate PETN pressing from donor end; 40 mg each.
Pressing Mode C: One PETN pressing from booster-pellet end; 80 mg.
Pressing Mode D: Two separate PETN pressings from booster-pellet end; 40 mg each.

maximum detonation velocity, the higher the density of the initiating PETN. A density discontinuity in the middle of the transition barrel seems to have little or no affect. As a result of these tests, all barrel-loading operations follow pressing Mode C (threaded end down).

ER-345 PARAMETER STUDIES

ER-345 detonators were fired with five different transition-barrel lengths and three column diameters. The PETN. (S = 3650 cm^2/g) loading-density range was 1.0 - 1.4 g/cm^3. The data are shown in Table VI. Only the results from barrels with a 2.5-mm bore are complete enough to analyze. These data indicate that the 50%-fire and all-fire lengths are near 7 and 9 mm, respectively, in this loading density range. The few experiments with smaller transition-explosive diameters do not indicate that a significantly shorter charge length can be used. Five-millimeter-long assemblies still fail most of the time. An increase in charge diameter may be helpful, however--3/4 of the 5-mm-long detonators at a low loading density functioned properly with a bore diameter of 3.8 mm. Experiments with PETN S values as high as 28,000 cm^2/g indicated best performance (with 9-mm-long transition barrels) was with the larger particle explosive loaded to the lowest density.

TABLE VI

Effect of Transition-Barrel Diameter, Length, and PETN Density on Firing Performance of ER-345 Detonators

PETN: S = 3650 cm^2/g

	Diameter = 2.0 mm		Diameter = 2.5 mm		Diameter = 3.8 mm	
			Transition-Barrel Length = 5 mm			
Density (g/cm^3)	F	Dent Vol. (cm^3)	F	Dent Vol. (cm^3)	F	Dent Vol. (cm^3)
1.0	--	--	0/5	--	3/4	0.3
1.2	1/3	0.3	0/5	--	--	--
1.3	--	--	3/4	0.3	--	--
1.4	--	--	0/5	--	--	--
			Transition-Barrel Length = 7 mm			
1.0	--	--	5/7	0.3	2/2	0.3
1.2	4/4	0.3	6/10	0.3	--	--
1.3	--	--	0/3	--	--	--
1.4	--	--	1/5	0.3	--	--
			Transition-Barrel Length = 9 mm			
1.0	--	--	3/3	0.3	2/2	0.3
1.2	3/3	0.3	8/10	0.3	--	--
1.3	--	--	3/3	0.3	--	--
1.4	--	--	5/5	0.3	--	--
			Transition-Barrel Length = 11 mm			
1.0	--	--	--	--	--	--
1.2	--	--	5/5	0.3	--	--
1.3	--	--	--	--	--	--
1.4	--	--	5/5	0.3	--	--
			Transition-Barrel Length = 14 mm			
1.0	--	--	--	--	--	--
1.2	--	--	10/10	0.4	--	--
1.3	--	--	--	--	--	--
1.4	--	--	--	--	--	--

F = Fraction Assemblies Achieving Detonation

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27, 28 and 29 September 1983

GENERAL DYNAMICS
Ft. Worth, Texas

TITLE In the Beginning/The Early Years

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ABSTRACT

This paper will be just what the title said it will be. A look back to 1956 when Robert L. Telford, Chairman, Bomb & Artillery Ammunition Division--American Ordnance Association, assisted Dr. Hubert Ellern in establishing the Military Pyrotechnic Committee.

Then the years of struggle--1956 to 1960. Believe me, dear friends, it was a struggle.

PROGRAMMATIC ENVIRONMENTAL ASSESSMENT FOR ARMY SMOKE/OBSCURANT PROGRAM

by

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Department of the Army (DA) programs are subject to numerous federal, state, and local environmental laws and regulations. Recognizing the need to advise and assist program managers to conform to these environmental requirements, the US Army Materiel Development and Readiness Command (DARCOM), has directed preparation of programmatic environmental assessments (PEA) for smoke/obscurant programs under DARCOM.

In these PEAs, provisions of the National Environmental Policy Act (NEPA) and other potentially important environmental regulations are discussed, with suggestions for compliance and mitigations. They also describe their role as a basic reference in the preparation of item- and site-specific environmental documentation for operations involving smoke/obscurant devices.

From an environmental perspective it is difficult to imagine sources of pollution more objectionable than military weaponry and munitions. Although the use of smoke/obscurant devices and materials are relatively minor when compared to the overall Department of Defense (DOD) programs they do produce potential sources of environmental pollution. The emissions and waste products from operation of these systems are subject to federal, state, and local environmental laws and regulations. Failure of DOD and other government agencies to comply with environmental legislation has resulted not only in needless adverse environmental impacts, but also in costly litigation, bad publicity, and program delay.

The purpose of this paper, then is to discuss environmental legislation most likely to affect research, development, and other activities of the pyrotechnic community. We also describe a Programmatic Environmental Assessment (PEA) prepared by our office to help simplify management of environmental requirements for smoke/obscurant operations of the major Army commands. This information should be usable as a reference document by all services when addressing their related programs.

ENVIRONMENTAL LEGISLATION

Environmental legislation has been enacted to preserve the quality of man's surroundings, including the air he breathes, the water he drinks and enjoys, and the ecology of native vegetation and wildlife. Environmental laws and regulations are of two types: 1) those requiring assessment of potential environmental impacts of specific programs or actions, and 2) those requiring compliance with environmental pollution standards. These are discussed briefly in turn below:

Environmental Impacts

The National Environmental Policy Act of 1969 (NEPA) was created by Congress to establish a national policy to protect the environment and to minimize adverse environmental consequences by requiring that impacts of planned federal actions and alternatives be evaluated before being undertaken.[1] This act is binding on activities of all federal agencies except where inconsistent with other statutory requirements (e.g., national security). Certain provisions of NEPA are also incorporated into other federal legislation, including the National Historic Preservation Act of 1966 and the Endangered Species Act of 1973.

Because federal programs vary greatly in potential to disrupt the environment, different formats have been created to document different degrees of environmental risk. These formats include the Environmental Impact Statement (EIS), Environmental Assessment (EA), and Record of Environmental Consideration (REC).

An EIS is a public document which is prepared to address actions which may "significantly" degrade environmental quality, public health and safety, and/or significant historic or cultural resources. The EIS must provide "full and fair" public discussion for all reasonable alternatives to an action to avoid or minimize adverse impacts to the human environment. The preparation, staffing, and public review procedures for EISs will generally require at least 10 months to complete. Many of the Army's EISs are prepared for specific projects or actions of the Corps of Engineers. Programmatic EISs are sometimes required, however, for congressional review of major Department of Defense actions, a recent example being the EIS for the Department of the Army's Binary Chemical Munitions Program.

In contrast, environmental impacts of routine Army activities are commonly addressed by means of a record of environmental consideration (REC). A REC is designed to reduce unnecessary environmental paperwork and is based either upon an existing EA or EIS, or upon types of activities given a specific Categorical Exclusion (CX). The Department of the Army currently lists 28 different CXs (e.g., routine maintenance, road repairs, military training, laboratory research), which are subject to continual review and revision.

Many Army actions, particularly within the Research and Development (R&D) community, are not categorically excluded from environmental documentation and, thus, must be addressed in an EA or EIS. The stated purpose of an EA is to determine "whether the proposed project or activity requires an EIS," but in most cases this decision has already been made, and the EA is prepared to address the action's potential for "measureable," but not "significant" degradation of environmental quality.

Whenever it is concluded in an EA that an action does not require an EIS, a brief "Finding of No Significant Impact" (FNSI) must be prepared. A FNSI is a legal notice and must be published to notify "potentially affected parties" before the start of the proposed action.

EAs can address specific actions or general programs, an example of the latter being the PEAs now being prepared for Army smoke/obscurant operations. DARCOM guidance[3] also encourages Life Cycle EAs, which address potential environmental impacts attending development, testing, production, and disposal of specific military materiel. Installation EAs address site-specific impacts of many important R&D, training, and Army production activities and, if properly prepared, can suffice as adequate documentation for activities otherwise requiring separate EAs.

Army policy in NEPA matters is provided in AR 200-2,[2] which establishes responsibilities and procedures for integration of environmental considerations into Army planning and decision making. Among these responsibilities are the identification and analysis of environmental risks for proposed actions and their most likely alternatives. DARCOM policy requires environmental analysis and documentation for all items (including smoke devices) being developed under its program/project/production managers and R&D commands.[3] In addition, site specific environmental documentation may be required for training and other exercises in which smoke/obscurants are involved.

In summary, it should be emphasized that EISs, EAs, and RECs are often useful planning documents that can alert project administrators to potential conflicts with other environmental requirements, some of which are discussed below, and thereby lessen chances of prolonged and costly program delays.

ENVIRONMENTAL POLLUTION STATUTES

Resource Conservation and Recovery Act

The Resource Conservation and Recovery Act of 1976 (RCRA) established a national program for management of waste, including hazardous waste (40 CFR parts 260-65; 267). Wastes are defined by RCRA as "hazardous" 1) if specifically listed by regulation, or 2) if exhibiting any one of the characteristics of reactivity, corrosivity, ignitability, or toxicity (as defined in 40 CFR; 261.2). The present EPA list includes approximately 400 chemicals and 85 process wastes. State regulations may also impose requirements not present in federal regulations.

Under RCRA, the generator of waste must determine whether or not it is hazardous. If found to be hazardous, the waste is then subject to comprehensive "cradle to grave" record keeping requirements, including a manifest system to track and document the generation, transportation, and ultimate disposal of the material in an authorized hazardous waste management facility. It should be emphasized that substances are not classified by RCRA as wastes until they are ready to be discarded. The regulations do not apply to the reuse, recycling, or reclamation of hazardous wastes, except that hazardous waste sludges and listed hazardous wastes are subject to certain requirements with respect to transportation and storage (40 CFR, 261.6).

Substances identified by EPA under RCRA as "acute hazardous" and "toxic" wastes are listed in 40 CFR, part 261.33. Other substances may qualify as hazardous waste by exhibiting one or more of the characteristics described above.

Toxic Substance Control Act

The Toxic Substance Control Act of 1976 (TSCA) addresses the manufacture, importation, distribution, and use of chemical substances (40 CFR, parts 704-710). This act authorizes the EPA to inventory commercial chemicals and, for chemical listed after 31 December 1979, to require sufficient data to estimate health and environmental hazards of production and use.

TSCA reporting and testing requirements will only effect Army smoke/obscurant programs if chemical substances used for research are 1) unlisted on the revised 1979 TSCA inventory (45 FR 505444, 29 July 1980), and 2) imported or produced primarily by the Army for its purposes.

Clean Air Act

The Clean Air Act of 1963 (CAA) was created because of public concern over health problems associated with air pollution (40 CFR, parts 50-52). The CAA authorizes a comprehensive regulatory program to achieve specific National Ambient Air Quality Standards (NAAQS). The EPA has promulgated NAAQS for certain "criteria pollutants," including sulfur dioxide (SO_2), total suspended particulates (TSP), photochemical oxidants, carbon monoxide (CO), nitrogen dioxide (NO_2) and "hydrocarbons." These standards define the quality of air that must be achieved and maintained to prevent adverse effects to national air resources, and were prepared specifically to protect human health and the quality of the environment. It is recognized that adverse effects can occur from brief exposures to high levels of pollution, or from long-term exposures to lower levels of pollution. Consequently, most NAAQS specify two types of limitations - long-term standards that cannot be exceeded on an annual average, and short-term exposures that cannot be exceeded for brief periods (e.g., 3 hours and/or 24 hours).

Under CAA, the country is divided into 247 air quality control regions (AQCRs) to provide basic geographical units for air pollution control. States are required to prepare State Implementation Plans (SIPs) to implement and enforce criteria pollutant standards in those regions. State standards are often more stringent than federal standards and vary from one AQCR to another.

Other Federal Regulations Governing Release of Hazardous Substances into the Environment

Policies and procedures for control of discharges of oil and hazardous substances into the environment are detailed in the Federal Water Pollution Control Act of 1947 (FWPCA)[4] and the Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA).[5] Section 311 of FWPCA describes requirements for handling of spills of oil and hazardous substances. A "spill" is defined as the release or discharge of regulated pollutants not covered by permit by pumping, pouring, emitting, emptying, leaking or dumping. EPA has promulgated regulations under the FWPCA which identify and establish reporting requirements for approximately 270 hazardous substances. Reporting requirements are based on harmful quantities as defined by the regulation.

CERCLA establishes reporting requirements for the release of hazardous substances into the environment, including land, air, and water when release occurs in amounts equal to or greater than the reportable quantity. As defined by CERCLA a hazardous substance is any substance designated or listed in: FWPCA, Section 307 and 311; RCRA, Section 3001; CAA, Section 112; and TSCA, Section 7. "A reportable quantity" for any of these substances is 1 pound, unless otherwise specified in Section 311 of the FWPCA.

Transportation of Hazardous Materials

The US Department of Transportation is required by federal law to formulate regulations for safe transportation of hazardous materials, poisonous substances, explosives, and other dangerous articles (49 CFR, parts 171-177). These regulations bind all carriers engaged in the transport of the above mentioned hazardous material and are in accordance with the best known practices for assuring safety in transit. Of particular importance is part 172 of these regulations which lists hundreds of materials by hazard class (e.g., "flammable," "corrosive") with guidelines for safe packaging and shipping. Additional guidance is provided elsewhere.[6]

Military Installations

Policies and procedures for environmental protection of Army installations are provided in AR 200-1,[7] "Environmental Protection and Enhancement". This regulation describes Army environmental management objectives in several important areas, including air pollution and water resources, solid and hazardous wastes, toxic and hazardous materials, noise abatement, and contingency plans for spills of oil and hazardous substances. Additional guidelines are provided in respective Major Army Commands (MACOM) and installation supplements to this regulation.

Requirements for shipment and storage of military items are provided in other Army regulations.[7,8,9,10]

It can be seen from the foregoing discussion that environmental laws and regulations place considerable demands on generators of environmental pollution. We have briefly reviewed regulations most likely to affect aspects of Army programs, and we emphasize that Army responsibilities under these regulations are not easily waived and should not be overlooked.

Project engineers and program administrators should recognize potential problem areas early in the course of a program. Advice and assistance in environmental matters can be provided by environmental staffs of most Army commands and/or by Environmental Coordinators. These specialists should be consulted to arrange for consultations with appropriate federal and state regulators over environmental problem areas. Once taken, these steps will greatly reduce chances of noncompliance with environmental statutes, thus eliminating potential sources of program delay.

PROGRAMMATIC ENVIRONMENTAL ASSESSMENT OF ARMY SMOKE/OBSCURANTS

The Environmental Technology Division, Chemical Research and Development Center (CRDC), was tasked by DARCOM (DRCIS-A) to prepare a Programmatic Environmental Assessment (PEA) for Army smoke/obscurant materials. A five (5) volume series has been prepared to cover the many different types of smoke/obscurant materials: Volume 1, Petroleum Type & PEG 200; Volume 2, Phosphorus Smokes; Volume 3, IR Smokes; Volume 4, HC Smokes; and Volume 5, Dye Colored Smokes. The initial draft of these PEAs were submitted throughout the Army smoke/obscurant community for information and comment. They were recently approved, and should greatly simplify DARCOM and other MACOM requirements for environmental documentation of operations involving Army smoke/obscurants.

The document has been prepared to serve as an environmental overview of the Army smoke/obscurant program. Emphasis is placed on potential impacts attending smoke/obscurant materials rather than specific hardware. It should be noted that the assessment of smoke/obscurant materials is compounded by the fact that one must address the environmental effects of the many degradation products of pyrotechnic smoke/obscurant materials as well as the original materials. This approach conforms to federal and Army requirements for environmental documentation and should also limit potential security classification and OPSEC problems regarding Army smoke/obscurants. With the exception of Volume 3, the current drafts do not reference classified sources and is intended for release to the general public.*

Topics include brief discussions of the history and organization of the Army smoke/obscurant program, research, testing, training, production, storage, transportation, demilitarization, disposal, health, safety, and environmental laws and regulations. Environmental impacts are addressed in terms of biological effects of smoke/obscurant materials and their degradation products, upon the flora and fauna as well as ancillary factors (meteorological, terrain, and geological, etc.) influencing propagation of smoke/obscurants in the atmosphere. Appendixes include discussion of such subjects as; dispersion models, meteorological aspects, and detailed toxicity data. One of the many benefits forthcoming from the preparation of the PEAs is the identification of knowledge and data gaps. Several areas have been identified where more environmental and related data are needed for better program decisions and thus better protection for the government. A few typical data gaps identified while preparing these PEAs are identified in Tables 1 - 5.

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*The information in Volume 3 is classified and not releasable to the public, the distribution of which would be limited to government agencies.

TABLE 1
Data Gaps: Petroleum & PEG 200

1. Environmental Fate/Effects
    a. Foliage - Growth & Germination rates
    b. Indirect Impacts - Foraging Animals (deer, rabbits, eagles, etc.)
    c. Long Term Effects
    d. Soil & Aquatic Toxicity
2. Identification of Combustion products in petroleum smokes
3. Human Toxicity. No historical data on troops, etc., working in cloud formations.

TABLE 2
Data Gaps: RP, WP

1. Identification of combustion products of RP-8B.
2. Measurement of deposition rates of combustion products.
3. Determination of Environmental Fate of Combustion Products in Soil and Aquatic Systems.
4. Measurement of unreacted WP in felt pads after use.
5. Determine if F_4 is deposited on the soil.

TABLE 3
Data Gaps: IR Materials

1. Deposition of IR materials on soil.
2. Soil Toxicity
3. Aquatic Toxicity
4. Environmental fate in soil and aquatic systems.
5. Transformation (corrosion) products.
6. Conducting EP Toxicity test to determine if material could be a hazardous waste.

TABLE 4
Data Gaps: HC Smoke

1. Environmental Fate of HC and byproducts on flora and fauna.
2. Quantify amounts of combustion byproducts.
3. Determine Status of HC Smoke for future use.

TABLE 5
Data Gaps: Dyes

1. Environmental fate of Dye and Combustion products.
2. Mammalian Toxicity Studies (USAMBRDL)
3. Soil and Aquatic Toxicity of Dyes and Combustion products.

LITERATURE CITED

1. Code 40 CFR, Environmental Protection Agency, parts 1500-1508, Regulations for Implementing the Procedural Provisions of the National Environmental Policy Act.

2. Army Regulation 200-2, Environmental Effects of Army Actions, Incorporating Change No. 1, 15 September 1982.

3. DARCOM supplement 1 to AR 200-2, 26 February 1982.

4. Code 40 CFR, Environmental Protection Agency, Subchapter D, Water Programs, Parts 110-114

5. Public Law 96-510, December 11, 1980, 94 Stat. 2727; 42 USC 9601 et. seq. Amended by Public Law 97-272, September 30, 1982.

6. Department of Transportation, DOT-P 5800.2, 1980, Emergency Response Guide Book, February 1981.

7. Army Regulation 200-1, Environmental, 15 June 1982.

8. Department of the Army Technical Manual 3-250, Storage, Shipment, Handling and Disposal of Chemical Agents and Hazardous Chemicals, March 1969.

9. Army Regulation 55-355, Military Traffic Management Regulation, 15 March 1969.

10. Department of the Army Technical Manual 38-250, Preparation of Hazardous Materials for Military Air Shipment.

VISIBLE SPECTRA OF STANDARD NAVY COLORED FLARES

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The visible spectra, color data and output powers from standard Navy yellow, red and green signal flares are presented. The dominant emissions are from molecular bands of the alkaline earth oxides, hydroxides and chlorides in the red and green flares and from atomic sodium in the yellow flare.

Enclosure (1)

INTRODUCTION

A recent search of the open pyrotechnics literature has shown the unavailability of the visible spectra of common in-service military colored flares. The visible spectrum of a highway red flare, similar in composition to the military red flare, has been published by Douda.[1] A new book by McLain has no visible spectra.[2] The most recent book in the field of pyrotechnics by Shimizu presents block diagram spectra of pyrotechnic flame emitters but no actual flare spectra.[3] Earlier studies have presented emission studies of special selected pyrotechnic flames but none of actual pyrotechnic devices.[4,5]

The purpose of this report is to present the actual flame spectra of in-service Navy pyrotechnic colored flares. These spectra were all taken on the same spectrograph under essentially identical conditions.

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1. B. E. Douda, Am. J. Optom. and Arch. Am. Acad. Optom. 49, 415 (1972).

2. J. H. McLain, "Pyrotechnics," (Franklin Institute Press, Philadelphia, 1980).

3. T. Shimizu, "Fireworks: The Art, Science and Technique," (Takeo Shimizu, Tokyo, Japan, 1981).

4. B. E. Douda, J. Opt. Soc. Am. 55, 787 (1965).

5. R. F. Barrow and E. F. Caldin, Proc. Phys. Soc. (London), B62, 32 (1949).

EXPERIMENTAL*

The flares burned in these experiments were standard Navy colored flare units. The red flares were Mk 124 Mod 0 Marine Smoke and Illumination Signals (MSIS). The green flares were Mk 117 Mod 0 Marine Smoke and Illumination Signals. The yellow flares were Mk 118 Mod 0 Marine Smoke and Illumination Signals. The flare compositions for these signals are given in Table 1. Data were taken for ten to twenty flare burns.

The flares were burned face-down at a distance of four meters from the spectrograph. No attempt was made to isolate any specific area in the flame. Visible spectra were taken with a Spex Model 1802 one-meter grating spectrograph. This spectrograph has a 1200 groove/mm grating blazed at 500 nm and gives a dispersion of 0.8 nm/mm in the first order in the region from 400 - 680 nm. Kodak Type 1-F and 103-F spectrographic plates were used for recording the spectra. The spectra were scanned and digitized on an Optronics S-2000 densitometer, and the film density was converted to radiant and luminous power readings using standard techniques.

Measurements of dominant wavelength, purity and candlepower were made with the Hunter tri-stimulus colorimeter currently used for all colored flare testing programs. This instrument

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*In order to specify procedures adequately, it has been necessary occasionally to identify commercial materials and equipment in this report. In no case does such identification imply recommendation or endorsement by the Navy, nor does it imply that the material or equipment identified is necessarily the best available for the purpose.

TABLE 1 - NAVY COLORED FLARE COMPOSITIONS

	Mk 124 RED	Mk 117 GREEN	Mk 118 YELLOW
Magnesium, MIL-M-382	24.4	21.0	30.3
Potassium Perchlorate, MIL-P-217	20.5	32.5	21.0
Strontium Nitrate, MIL-S-20322	34.7	----	----
Barium Nitrate, MIL-B-162	----	22.5	20.0
Polyvinyl Chloride, MIL-P-20307	11.4	12.0	----
Sodium Oxalate, JAN-S-210	----	----	19.8
Copper Powder, MIL-C-768	----	7.0	----
Asphaltum, MIL-A-356	9.0	----	3.9
Binder, MIL-STD-708	----	5.0	5.0

has four filter/detector combinations designed so that the filter plus detector response curves match as closely as possible the CIE color-matching functions $\bar{x}$, $\bar{y}$ and $\bar{z}$. Measurements from each detector then give the tri-stimulus values X, Y and Z which are defined as:

$$X = k \int I(\lambda)\, \bar{x}(\lambda)\, d\lambda$$
$$Y = k \int I(\lambda)\, \bar{y}(\lambda)\, d\lambda$$
$$Z = k \int I(\lambda)\, \bar{z}(\lambda)\, d\lambda$$

where k is a normalization constant and $I(\lambda)$ is the intensity of the source at wavelength λ. The chromaticity coordinates, x and y, can be calculated using X, Y and Z. The values of dominant wavelength and purity are then determined by a standard graphical method after plotting the chromaticity diagram.[6] The average experimental error in dominant wavelength is ± 2 percent and in excitation purity is ± 5 percent. The Hunter cell which gives the tri-stimulus value of Y is calibrated against an NBS traceable standard lamp to give the value of candlepower. The experimental error in candlepower is ± 7 percent.

RESULTS

The visible radiant power spectra of the Mk 124 MSIS red flare, the Mk 117 MSIS green flare and the Mk 118 MSIS yellow flare are shown in Figures 1, 2 and 3, respectively. Each spectrum is normalized to a value of one at its maximum. Approximately five spectra were taken during each flare burn.

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[6] D. B. Judd and G. Wyszecki, "Color in Business, Science, and Industry," Third Edition, (John Wiley and Sons, Inc., New York, 1975), pp. 170-172.

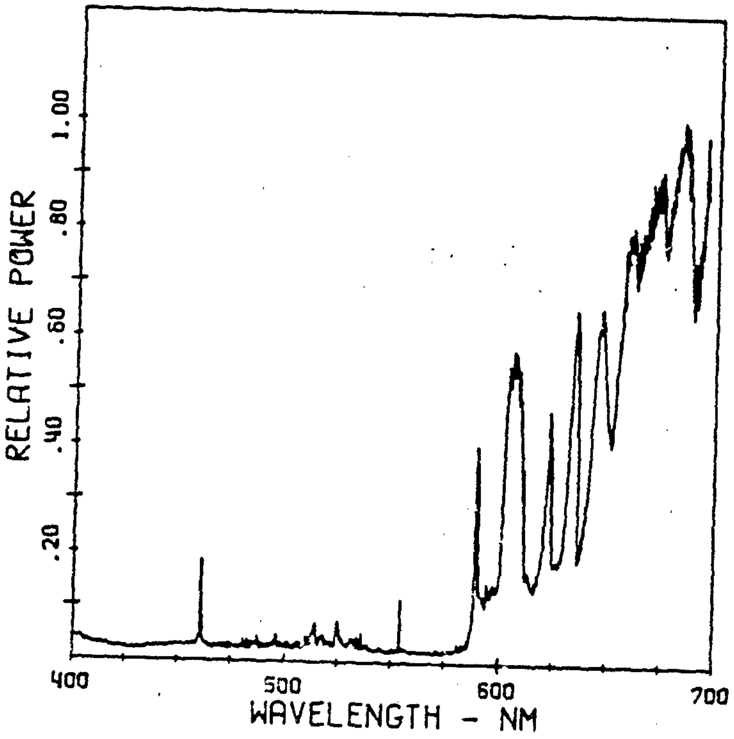

Figure 1. Radiant Power Spectrum for Mk 124 Red Flare.

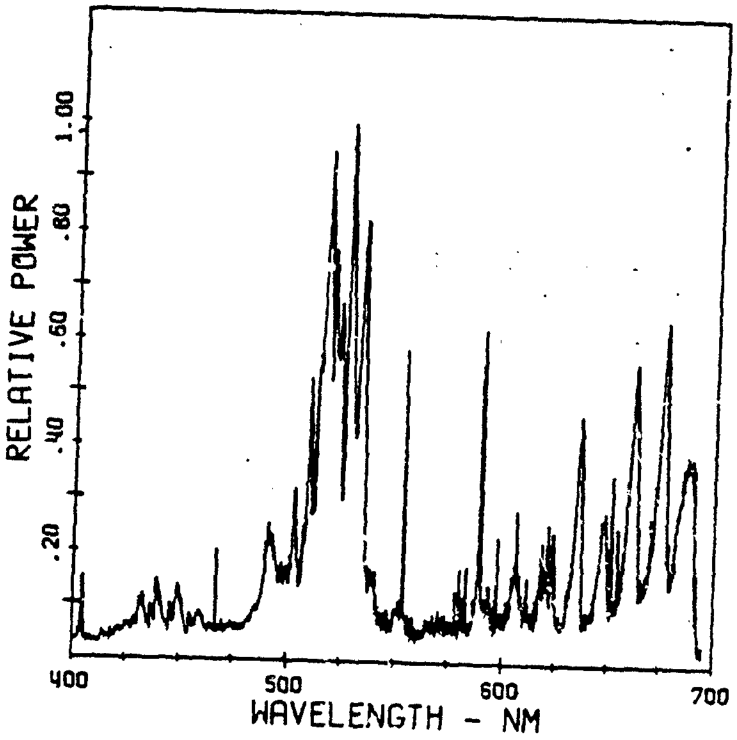

Figure 2. Radiant Power Spectrum for Mk 117 Green Flare

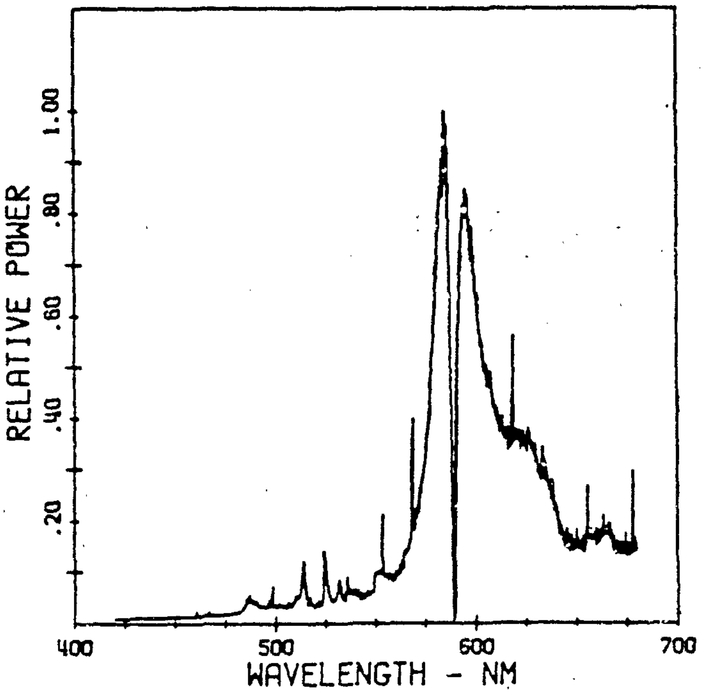

Figure 3. Radiant Power Spectrum for Mk 118 Yellow Flare

Figures 1-3 represent a single flare spectrum and were selected as being representative of the entire group of spectra taken. Little deviation was observed among individual flare spectra taken within a single burn and also among spectra from different flares.

The average luminous intensity for the Mk 124 Mod 0 MSIS was 8700 cd and the burn time was 18.5 seconds for a flare weight of 24 grams. The average dominant wavelength was 610 nm and the excitation purity was 96 percent. The flare color appeared red to the eye.

The average luminous intensity for the Mk 117 MSIS was 19400 cd and the burn time was 26 seconds for a flare weight of 140 grams. The average dominant wavelength was 558 nm and the excitation purity was 47 percent. The flare color apoeared greenish-white to the eye.

The average luminous intensity for the Mk 118 MSIS was 29100 cd and the burn time was 35 seconds for a flare weight of 140 grams. The average dominant wavelength was 584 nm and the excitation purity was 82 percent. The flare color appeared yellowish-white to the eye.

DISCUSSION

Mk 124 MSIS Red Flare

The radiant power spectrum of the Mk 124 Mod 0 MSIS red flare is shown in Figure 1. The primary emitting species in the red flare are SrCl and SrOH. Emission bands from the SrCl $A\ ^2\pi \rightarrow X^2\Sigma^+$ system are observed at 661.4 nm, 662.0 nm, 674.5 nm and 675.6 nm. Emission from the SrCl $B\ ^2\Sigma \rightarrow X\ ^2\Sigma^+$

system is observed at 623.9 nm, 636.2 nm, and 648.5 nm. The bands in both these systems show sharp band-heads and are degraded to the violet. Although they are not shown in Figure 1, emission bands from the SrCl $C\,^2\pi \rightarrow X^2\Sigma^+$ system were observed at 393.7 nm, 396.1 nm and 400.9 nm. Molecular emission from the SrOH band system is observed in Figure 1 at 605.0 nm, 646.0 nm, 659.0 nm, 667.5 nm and 682.0 nm. The bands at 646.0 nm, 659.0 nm and 667.5 nm overlap the SrCl bands at those wavelengths. This makes the SrCl bands appear stronger and more diffuse than would normally be expected.

Atomic emission is observed at 460.7 nm from strontium, 553.5 nm from barium and 589.0 nm and 589.6 nm from sodium. Also apparent in Figure 1 are molecular emission bands at 513.8 nm, 516.2 nm, 524.1 nm and 532.1 nm from the $C\,^2\pi \rightarrow X^2\Sigma$ system in BaCl. The barium and sodium are present only as impurities. Atomic emission lines from potassium are present throughout the visible spectrum but are not strong enough to appear in Figure 1. Emission bands from SrO in the region from 400 - 470 nm are not observed.

In order to evaluate the major contributors to the perceived color of the flare it is necessary to convert the radiant power spectrum shown in Figure 1 to a luminous power spectrum. This is done by applying the CIE color-matching function, $\bar{y}$, to the radiant power spectrum.[6] When this is done it is found that the primary emitter in the red flare is the SrOH molecule. The SrCl and SrOH bands above 650 nm do not contribute significantly. Their major effect is to shift the dominant wavelength to slightly longer wavelengths. The hydrogen needed to form the SrOH comes primarily from the decomposition of the polyvinyl chloride. If one wanted to increase the dominant wavelength (and thus make the light appear redder), a donor such as polytetrafluoroethylene could conceivably be substituted for the polyvinyl chloride. The primary emitter would then be SrF which has emission bands from 628 - 688 nm. However, the success of the current composition leaves little to be desired.

This spectrum can be compared to the spectrum reported by Douda of a red highway flare used by motorists for emergency signaling.[1] The red highway flare has a formula that is typically 74% strontium nitrate, 6% potassium perchlorate, 10% sulfur and 10% grease, wax and other ingredients.[7] The spectrum for the highway flare is similar to the spectrum obtained for the Mk 124 MSIS. The primary emission is from SrOH at 606 nm with some contribution from SrOH bands at 646 nm, 659 nm, 668 nm and 682 nm. These bands all overlap the SrCl band regions, making it difficult to determine the extent to which SrCl adds to the overall emission. The spectrum of the highway flare does show a band at 636 nm which could be assigned to SrCl. The band at 624 nm is not present in the highway flare. This fact, coupled with the very small amount of chlorine available in the formula, leads to the conclusion that emission from SrCl does not make a significant contribution to the total power obtained in the highway flare.

Mk 117 Mod 0 MSIS Green Flare

The radiant power spectrum of Mk 117 Mod 0 MSIS green flare is shown in Figure 2. The primary emitting species in the green flare are BaCl and BaO. Emission bands from the BaCl $C\ ^2\pi \rightarrow X\ ^2\Sigma$ system are observed at 507 nm, 514 nm, 524 nm, and 532 nm.

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[7] H. Ellern, "Military and Civilian Pyrotechnics," (Chemical Publishing Company, Inc., New York, 1968), p. 362.

The molecular BaCl emission is superimposed on less intense, but equally important BaO, BaOH, and Ba_2O_2 band emissions extending from 460 nm to 678 nm. This emission, coupled with an underlying continuum from hot solid particles, is the contributing factor to the loss of color purity in this flare. The Mk 117 flare composition also contains copper and the resulting CuCl emissions are observed from 412-470 nm.

The most interesting part of this spectrum are the emission bands at 624 nm, 636 nm, 648 nm, 662 nm, and 675 nm. These bands are a result of SrCl emission and are not a part of any barium atomic or molecular emission system. The strontium is most likely present as an impurity in the barium nitrate. While emissions from impurity constituents are quite common in pyrotechnic flares, they are usually a negligible part of the total emission. The most common impurity is sodium which seems to be present in almost all compositions. However, even with its excellent emission properties, as an impurity it seldom accounts for more than 1% of the total power. The molecular emission from SrCl in the case of this flare accounts for almost 22% of the total radiant power. When the radiant power spectrum is converted to luminous power the significance of this added emission is greatly reduced. The added SrCl emission does, however, tend to increase the dominant wavelength and reduce the color purity further complicating the manufacture of a good green signal. It should also be pointed out that this SrCl emission is not an isolated event but is observed in all compositions containing barium nitrate and a chlorine donor.

Mk 118 Mod 0 MSIS Yellow Flare

The radiant power spectrum of the Mk 118 Mod 0 MSIS yellow flare is shown in Figure 3. The primary emitting species in the yellow flare is atomic sodium. The emission appears as the reversed and broadened sodium resonance lines at 590 nm. The broadening at half intensity is 25 nm which is theoretically consistent with a flame temperature slightly lower than the magnesium-sodium nitrate flare and a 20 percent sodium oxalate concentration.[8]

The sodium resonance lines are superimposed on a background continuum resulting from a combination of graybody emission and molecular emission from barium oxide, barium hydroxide and barium chloride (BaCl). Barium hydroxide emissions are observed at 487 nm and 512 nm. Barium chloride emissions are observed at 514 nm, 524 nm and 649 nm. The other barium oxide emissions are masked by the sodium resonance continuum. The shoulder on the long wavelength side of the sodium resonance lines ($605<\lambda<650$ nm) is a result of a number of barium oxide bands at 604 nm, 610 nm, 617 nm, 622 nm and 629 nm. Atomic barium lines are present at 554 nm and 660 nm. There is also emission from magnesium oxide at 500 nm.

An analysis of the formula and the visible spectrum of the standard yellow flare composition shows the reason for the lowered excitation purity in a flare which should be reasonably a much higher purity (>95%). Apparently when the yellow formula was developed it was done by simply adding sodium oxalate to a standard green flare formula. This was done

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[8] B. E. Douda and E. J. Bair, J. Opt. Soc. Am. 60, 1257 (1970).

primarily to keep development costs down and to hold down the cost of the item. The color and intensity are considered adequate for the signal as it now exists.

CONCLUSIONS

The output of the red flare composition used in the Mk 124 Mod 0 Marine Smoke and Illumination Signal comes primarily from SrCl and SrOH molecular species emitting at wavelengths greater than 605 nm. The flare produces 8700 cd for 18 seconds with a dominant wavelength of 610 nm and an excitation purity of 96 percent. Atomic emission from potassium, sodium and barium and molecular emission from BaCl are observed. This emission adds little to the overall output of the flare. The potassium is present from the potassium perchlorate oxidizer. The sodium and barium are present as impurities in the potassium perchlorate and strontium nitrate ingredients.

The output of the green flare composition used in the Mk 117 Mod 0 Marine Smoke and Illumination Signal comes primarily from BaCl and BaO molecular species emitting in the region from 500 nm - 540 nm. The flare produces 19400 cd for 26 seconds with a dominant wavelength of 558 nm and an excitation purity of 47 percent. Molecular emissions from BaO, BaOH, Ba_2O_2 and SrCl are also observed. These emissions, coupled with an underlying continuum from hot particles, contribute to the low color purity in this flare.

The output of the yellow flare composition used in the Mk 118 Mod 0 Marine Smoke and Illumination Signal comes primarily from atomic sodium emission at 590 nm. The flare produces 29100 cd for 35 seconds with a dominant wavelength of 584 nm and an excitation purity of 82 percent. The sodium resonance lines are superimposed on a background continuum resulting from a combination of graybody emission and molecular emission from barium oxide, barium hydroxide and barium chloride (BaCl).

A LOW ENERGY ROCKET MOTOR (LERM)
FOR USE WITH SMOKE COUNTERMEASURE PROJECTILES (U)

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1. (U) INTRODUCTION

(U) With the successful flight testing this past year, the initial exploratory development program for the Smoke Countermeasure Grenade Projectile has been completed. In order to expand the possible applications for such a smoke system, two distinct propulsion systems are being tested. The past flight tests proved the reliability of the ejection type of propulsion system. However, the severe setback forces quickly damaged critical parts of the launcher. Since weight is a critical factor in the development of this system, strengthening of the launcher was impractical. Thus, the only option available was to decrease the setback force from the projectile launch.

(U) This paper will cover the design and application of a short duration burn, low energy rocket motor to the Smoke Countermeasue Projectile Program. It will cover the flight stabilization of the projectile, the improvement of the pyrotechnic delay train and burster assembly, and the potential for replacement of the current propulsion system with the Low Energy Rocket Motor.

2. (U) DESIGN SUMMARY OF THE SMOKE COUNTERMEASURE PROJECTILE

(U) The first application of the Smoke Countermeasure Projectile was as self protection for attack helicopters. During the one year exploratory development program several changes were made in the design of the system. The final configuration was cylindrical, with a length of 15.125 inches for the polypropylene projectile and 16.0 inches for the aluminum launch tube. The projectile diameter was 2.350 inches with a 0.625 inch wide shoulder 2.470 inches in diameter. This shoulder acted as a gas seal and lowered the frictional bearing surface of the projectile. Figure 1 shows a cross-sectional view of the projectile and launch tube. The total projectile weighed about 1000 grams with 900 grams net fill of a phosphorus smoke composition. The muzzle velocity was 160 feet per second with a delay time of 1.0 second. The smoke cloud was formed at that 1.0 second interval after launch by a central burster.

3. (U) PYRO DELAY AND BURSTER

(U) After much deliberation on safety, cost, and performance, a simple pyrotecnic delay burster scheme was chosen. An aluminum delay housing with a 1000 millisecond (1 second) pressed pyrotechnic delay with a simple flash output would be the only metal part in the entire design.

(U) A modified photoflash burster was chosen as having the best flame and gas output available for this application. A high explosive burster was unacceptable due to cost, availability, and the need for an in-line lead azide charge. For a first cut at chosing a particle size for the modified photoflash blend, a nominal 60 mesh was chosen. All components of the mixture were sized to be as close to this diameter as possible.

(U) Blending was first attempted by using an acetone/viton rubber solution precipitated by hexane. This yielded a fine powder blend with the particles coated by a thin rubber membrane. Ignition of this mixture at ambient conditions was excellent, but some concern was present as to the reduction in output at sub zero temperature conditions.

(U) After much testing and evaluation, the final choice of delay/burster system was a dry blended modified photoflash powder burster with a high gas and flame output pyrotechnic delay. The delay is shown in figure 2. The output end contains two black powder pellets with a central core in each one. When ignited this delay reliably outputs a 12 inch long flame at the conclusion of the 1 second delay. This was sufficient to ignite either of the photoflash blends (dry or rubber coated) under all temperature ranges of concern.

4. (U) ITLX

(U) A third type of burster material was tested and found highly sucessful in this application. This material is named ITLX and is manufactured by Explosive Technology. With a propagation velocity 1350 meters per second, a caloric output of 1750 cal per gram coreload, specific energy of 60,000 Joules per kilogram and a gas output of 285 cubic centimeters per gram coreload, this proved to be a very interesting material. It is similar to the primacords but requires only a flame input to begin propagation. Tests with one, two, and three strands of ITLX as a replacement for the photoflash powder yielded satisfactory results.

(U) Unfortunately, this material did not arrive in time to be used during the final testing of the Smoke Countermeasure Projectile. Its use is anticipated in any improvement program to reduce the hazard of blending and charging with photoflash powder,however modified.

5. (U) STABILITY ANALYSIS AND CORRECTION

(U) The basic cylindrical projectile configuration is aerodynamically unstable and tumbles in flight. As stated above the "tumble stabilized" mode was the one of choice for the application of this projectile to helicopter use. However, it was felt that other applications of this projectile may require some form of stabilization.

(U) A simple ribbon stabilizer was initially considered. This was composed of a 1.0 inch wide strip of parachute tape attached to the aft end of the projectile. If a sufficient length, this ribbon will provide drag stability. Unfortunately, this projectile required a 30.0 inch length of ribbon to sufficiently stabilize it.

(U) Although this configuration did fly extremely well, packing requirements dictated that the ribbon be attached to the forward end of the projectile. This would require the projectile to make a 180 degree yawing motion as it left the launcher. Before any residual yaw could be dampened out, the projectile had already functioned. The large yawing motion produced considerable drag and effectively defeated the purpose of the stabilizer.

(U) After coordination with the Aerodynamics Research and Concepts Assistance Section of the Chemical Research and Development Center, the agreement was made to attempt the application of a fin stabilization technique. The initial trials used a simple four fin arrangement located at the aft end of the projectile. These four spring steel fins would be wrapped around the outer surface of the projectile body while it was inside the launch tube. Upon exiting the tube the fins would deploy tangentially and provide the stability required with a minimum of drag.

(U) A full scale model was fabricated for the purpose of wind tunnel testing. This model was made with two different configurations of fins. Each was independently evaluated. Both fin designs had chords of 2.0 inches. One set of fins had a length of 1.84 inches which would cover a 90 degree segment of the projectile outer body while inside the launch tube. The other set of fins had a length of 2.77 inches.

(U) In addition, the projectile wooden model was fabricated with two independent nose configurations, blunt as in the original design, and radiused. Figure 3 shows the outline of the wooden test model and the fin placement.

(U) Wind tunnel tests were conducted at an operating velocity of 160 feet per second. Yaw angles of approximately 40 degrees were induced. The results were recorded on strip recorders and later analyzed.

(U) The drag coefficients produced by these tests were used in a planar trajectory computer program to acertain the projectiles path in the air during various times in the flight. The drag coefficient for the tumbling mode (with no fins) was 6, yielding a ballistic coefficient of 10.1 lbs/ft2 for the two pound projectile. After 1 second of flight the projectile has traveled 125 feet horizontally and has dropped 14 feet vertically. With the smaller fins, the drag coefficient was reduced to 1.0, resulting in a ballistic coefficient of 60.6 lbs/ft2. In this configuration the projectile has traveled 152 feet horizontally and dropped 15.5 feet vertically after 1 second of flight. If the rounded nose is used with the small set of fins the drag coefficient is further reduced to 0.4. This is the lowest realistic drag possible. After 1 second of flight this configuration traveled 157.0 feet horizontally and dropped 16.0 feet vertically.

6. (U) THE CURRENT PROPULSION UNIT

(U) With the design requirement that a minimum of metal parts be airborne at launch, the choice of propulsion systems was considerably narrowed. The final system chosen was a simple black powder lifting charge embedded in the base of the aluminum launch tube.

(U) The launch tube was made from two components; an extruded tube, and the turned base. They were welded together. The base had a straight through 2.0 inch female thread into which screwed the propulsion unit.

(U) This unit was fabricated from a plastic rod and heldthe 4.5 grams of black powder in a recessed area. The volume of the black powder nearly filled the volume of the recessed area. A M-105 match was used as the electrical igniter. Two concentric brass rings at the base exterior served as the electrical contact point.

(U) The launch tube needs no additional support to function reliably. It is strong enough to withstand moderate handling when in its protective cardboard shipping tube. Although it can withstand launch pressures, it passes shock waves and recoil impulse directly to the launcher. It is this action which caused the helicopter launcher severe problems and was the cause of several malfunctions. The only answer was to design some type of low impulse propulsion system.

7. (U) THE LOW ENERGY ROCKET MOTOR DESIGN

(U) In applying the low energy rocket motor to the Smoke Countermeasure Projectile, several initial design critieria had to be established. These initial requirements were:

1. Outside diameter not to exceed 2.470 inches (same as projectile). (U)
2. Overall length not to exceed 6.0 inches (3.0 to 4.0 inches desirable). (U)
3. Motor must be capable of accelerating a 1000 gram projectile a minimum of 100 feet per second (200 feet per second desireable). (U)
4. Flame transfer through the front of the motor is mandatory. (U)
5. Ignition must be from the rear end. (U)

(U) High energy HEN-12 rocket propellent was chosen to meet the requirements for this low energy rocket motor. Past experience by AAI Corporation showed consistent and highly successful results in similar designs. Figure 4 shows a cross section of the latest design of the LERM.

(U) The desired performance of the rocked motor was to attain 60 meters range in 1 second. The average velocity required is approximately 200 feet per second. For a 1000 gram projectile and an assumed weight of 170 grams for the motor, the impulse necessary to reach 200 feet per second is 16 lb-sec.

(U) The operating chamber pressure was chosen as 1500 PSI, at which the burn rate of HEN-12 propellant is 1.05 in/sec. Unfortuantely, the availability of only 0.080 inch thick sheet delimited the choice of burn time to 0.040 second. Thus the average thrust is 400 pounds for an impulse of 16 lb-sec.

(U) The predicted performance for a constant 400 lb thrust applied over a 40 msec period of time was investigated by the AAI Corporation for Chemical Research and Development Center. AAI's thrusted missile trajectory computer program was used under contract.

(U) The results of this contract yielded a nozzle design, throat diameter, and burning surface area. Additionally, a test motor was fabricated by AAI Corporation, tested, and delivered to Chemical Research and Development Center at the conclusion of the contract.

(U) For ease of assembly, the propellent grain, igniter and propellant screen (retainer) are contained in a separate cup which is easily inserted into the chamber of the rocket motor. The purpose of the propellant screen is to retain the propellant grain when it is subjected to g-loading during the thrust phase. The base plate of the rocket motor is designed to accommodate the delay body, and the propellant cup incorporates a flame transfer hole leading to the delay.

8. (U) INITIAL STATIC TESTING OF THE LERM

(U) Thrust traces recorded by the AAI Corporation showed a peak thrust of 400 pounds. This matches the initial design calculations and is a reproducible result. A neutral burning propellant system was chosen over a progressive burning rate system due to the design criteria of low overall weight. Oscilloscope traces provided by the AAI Corporation to Chemical Research and Development Center showed the thrust of the rocket motor drops steadily from the peak of 400 pounds to approximately 200 pounds before trailing sharply to zero towards the end of the thrust phase.

(U) Due to funding and time constraints dynamic testing of the entire Smoke Countermeasure Projectile with the low energy rocket motor will be delayed until fiscal year 1984.

HELICOPTER SMOKE COUNTERMEASURE GRENADE

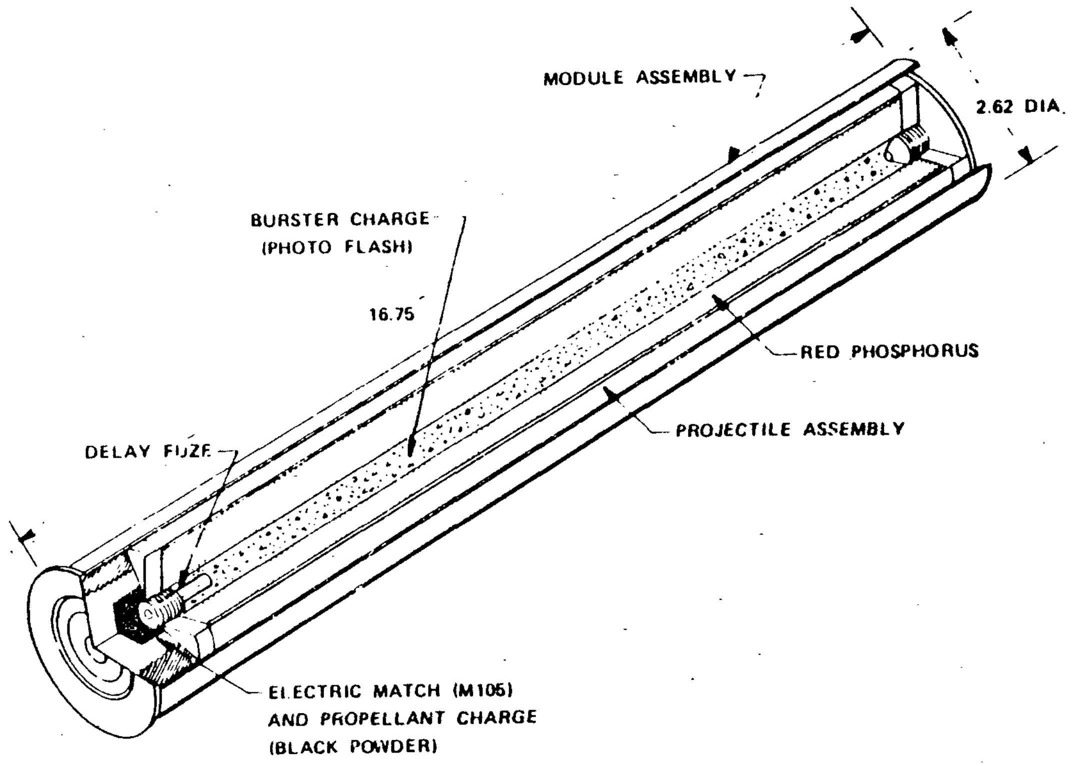
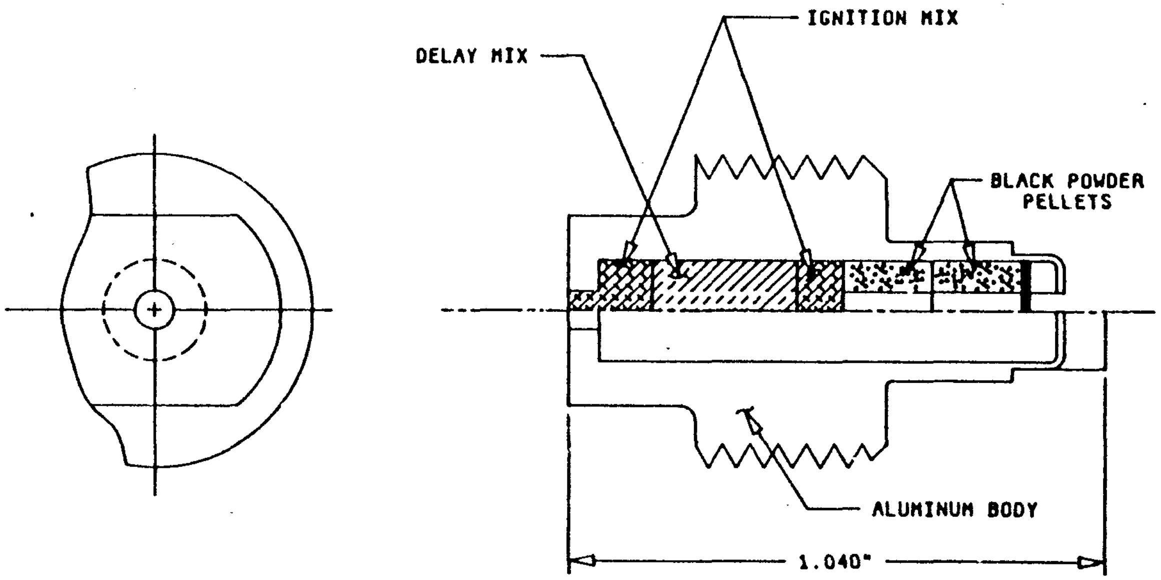
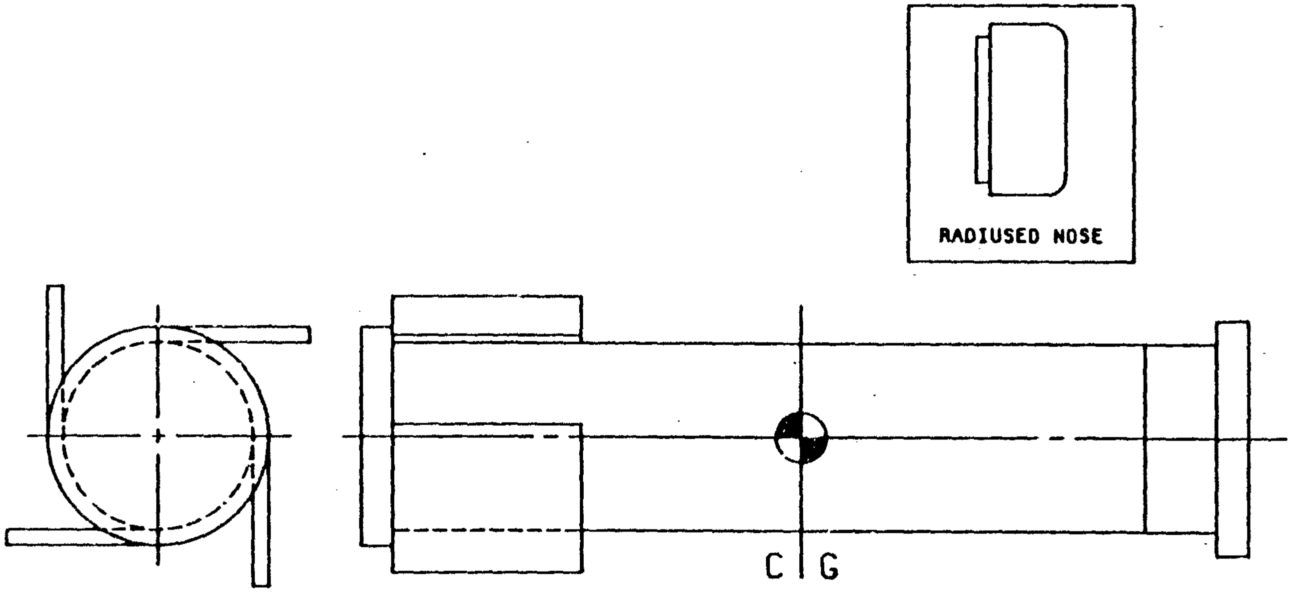


Figure 1. (U) Helicopter Smoke Countermeasure Grenade cross sectional view.


IGNITION MIX
DELAY MIX
BLACK POWDER PELLETS
ALUMINUM BODY
1.040"

DELAY BODY

Figure 2. (U) Pyrotechnic delay design.



BASIC SMOKE PROJECTILE WITH FINS

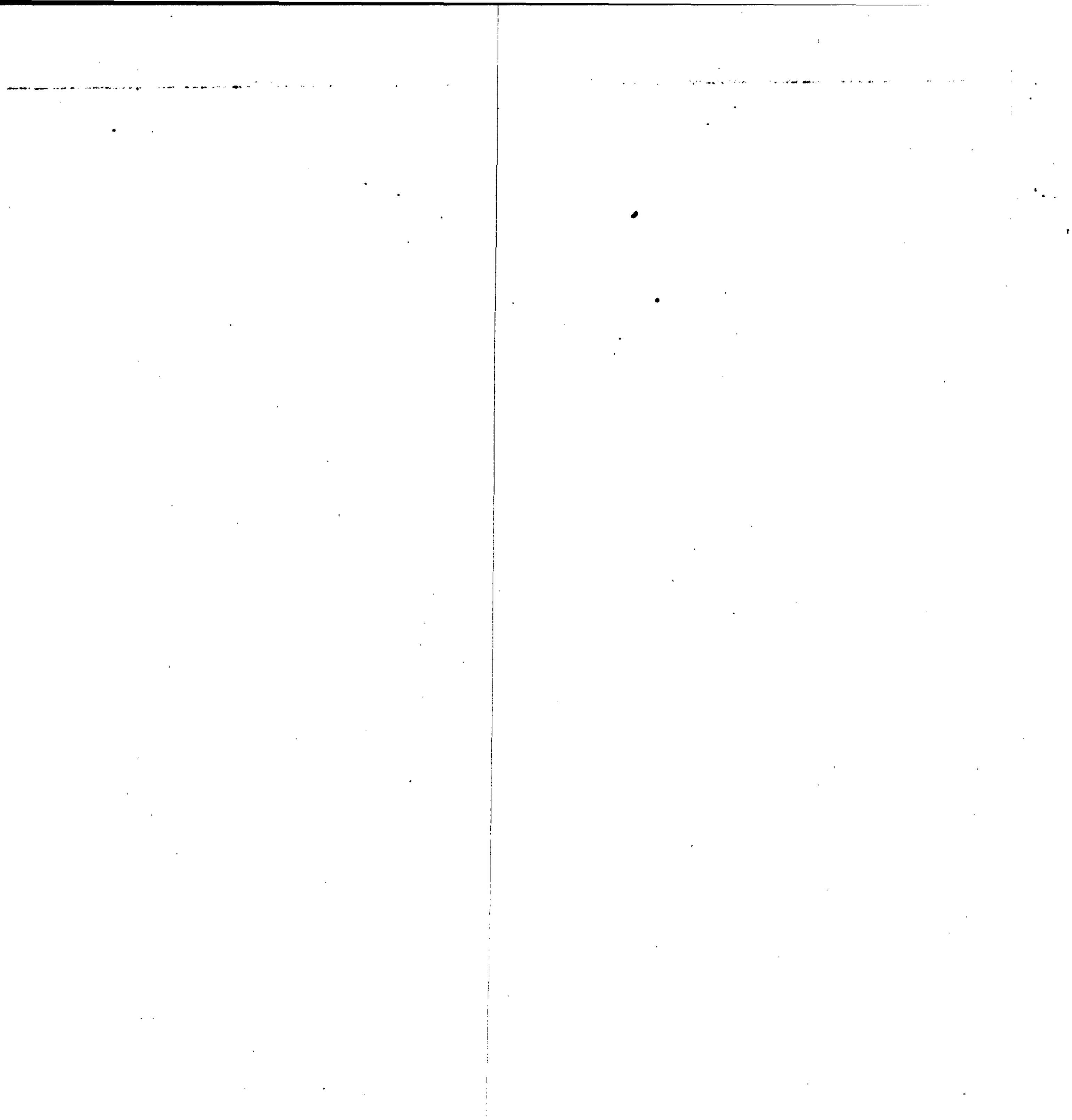
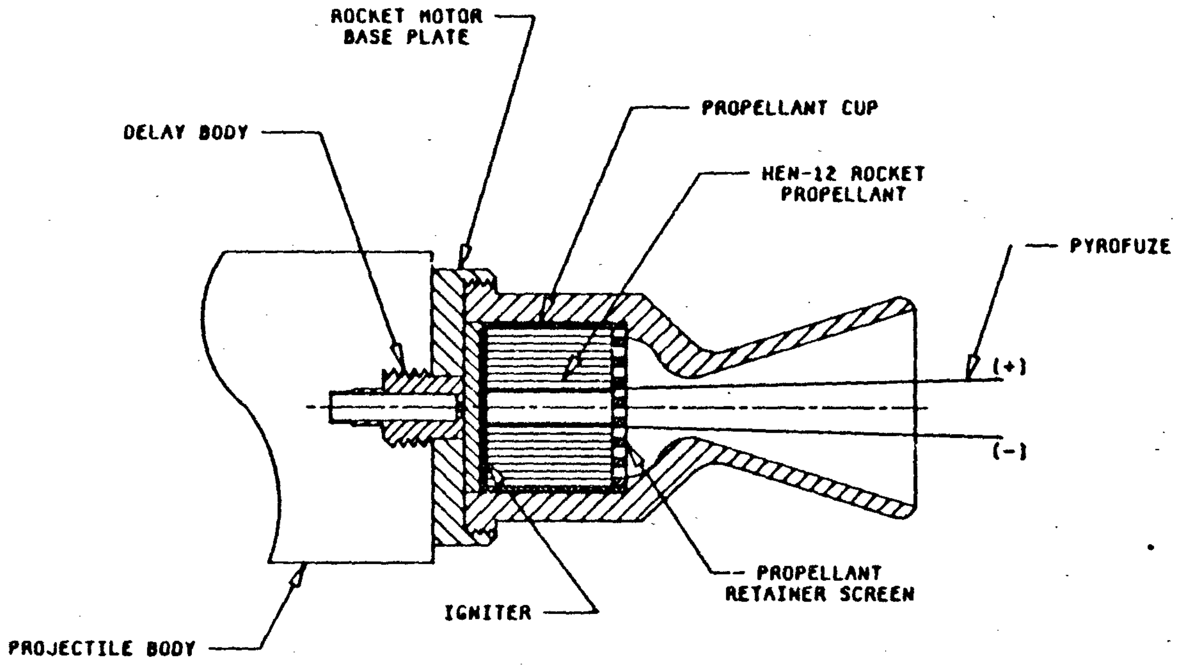


Figure 3. (U) Flight test model outline.



LOW ENERGY ROCKET MOTOR

Figure 4. (U) Low Energy Rocket Motor cross section.

SPRAYS AND SUBMUNITIONS:
TWO CONCEPTS FOR THE 81MM IR SMOKE CARTRIDGE (U)

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1. (U) INTRODUCTION

(U) The application of IR screening materials to mortar cartridges such as the 81mm mortar may possibly be accomplished by bulk filling methods. However, to look at only one concept for the dispersion of such material may prove to be too nearsighted. This paper will discuss two alternate filling techniques for application to IR smoke mortar cartridges or similar ammunition delivery systems.

(U) The first is the "thixogel" canister system of dispersion. This long duration spray canister concept is in direct contrast to the second proposed dissemination technique. This second concept is named the "submunition" concept, and is not new in the ammunition community. Its application in this case is new due to the specific functioning method of the individual submunitions.

(U) This paper will present both potential exploratory development concepts and their application to the 81mm mortar. The advantages and disadvantages of each concept will be compared.

2. (U) THE THIXOGEL SPRAY CONCEPT

(U) The spray canister concept uses an IR screening powder combined with a pyrotechnic heater and visible smoke cartridge. The canister itself contains 900 grams of a pressurized thixotropic blend of the IR powder in a high vapor pressure liquid freon. By carefully choosing the accompanying pyrotechnic heat/smoke mixture and the correct nozzle design, an effective visual and IR screening cloud can be obtained.

(U) The special exterior ballistic design allows the canister to implant itself upright in either hard or soft soil. This allows a maximum amount of IR powder to be expelled, resulting in an efficient dissemination system.

(U) The canister design is a one pound fire extinguisher cylinder. It is make of impacted extruded aluminum and is the proper outside diameter to slip into the illumination mortar body. A dip tube of flexible tygon tubing fitted with a "clunk" or a rigid aluminum tube is used inside the canister to aid in the expulsion of the powder. Figure 1 shows the initial canister design before any of the necessary "frills" were added.

(U) Several nozzles were tested during the initial concept phase of the exploratory development program. After successful operations with such sophisticated nozzle designs as the ultrasonic nozzle, the swirl chamber nozzle and the spiral nozzle, the current nozzle choice is an oil burner type nozzle is a simple hole of the proper diameter in a closure plate. The nozzle diameter is then the critical factor in the dissemination time.

(U) During the spray tests using a variety of powders to be disseminated one problem was ever present. All useable nozzle designs had a severe tendency to clog regardless of what type nozzle or material was used. The only reliable method was to increase the operating pressure of the canister which defeated the overall efficient lightweight design of the system.

(U) The only feasible answer was to incorporate a system which increased the operating pressure after the canister had already impacted the ground and was beginning to function. This system was of course pyrotechnic in nature. After initial calculations indicated that temperature was not as important as duration the slowest pyrotechnic mixture that would still reliably burn was used. This is a red phosphorus based mixture pressed at a dead load over what it would experience at launch in the mortar tube

(U) The configuration of where to put the pyrotechnic heater/smoke portion of the system without any parasitic effect resulted in the hollow nosecone of the cannister being filled with the material. A nominal amount of net fill was sacrificed from the IR powder portion.

(U) With the addition of a fin stabilizing arrangement and an impact pyrotechnic fuze, the canister system began to take its final shape. Figure 2 shows the exterior design of the current canister body.

3. (U) THE MULTIPLE SUBMUNITION CONCEPT

(U) The second concept employs individual submunitions within the canister body. The overall design of the concept overcomes the weak link in all previous designs. Regardless of the large variance in the height of the burst of the M84 series pyrotechnic time fuze, the resulting screening signature is expected to be nearly the same under similar conditions. The current design contains over 60 cylindrical submunitions within the canister body.

(U) The individual submunition design consists of a small pistol primer with firing pin and a tube body. This body contains 29 IR screening pyrotechnic pellets surrounded by ignition powder. Upon impact, the primer functions causing a large thermal image and ejecting the pellets out of the top end of the tube body. The pellets cause IR screening in both their ascent and descent. They continue to provide additional screening as they burn on the ground. Figure 3 shows a cross section of one submunition.

(U) The overall cartridge design holds over 60 of these submunitions in a single canister arrangement. Upon functioning of the M84 series pyrotechnic time fuze, the safety wires are burned away allowing the submunitions to be expelled and armed. After a short time of flight a "ground impact pattern" has formed due to the differences in overall weight of each submunitions. This pattern is held constant by the terminal velocity of the submunitions and is less affected by wind due to their low cross sectional area. Figure 4 shows a cross section of the loaded mortar body.

4. (U) RESULTS OF COMPARISON

(U) Each of the two concepts possess inherent advantages and disadvantages.

(U) The advantage of the thixogel concept is that it is material independent. As better IR screening materials become available, they can be directly applied to this canister. Additionally, it uses two separate parts to provide screening in two wavelengths. This allows the most efficient materials to be used for the wavelengths of concern.

(U) The advantage of the submunition concept is the high use of the available volume to correspond to maximum IR output as a function of weight. The individual submunitions are not subject to defeat by enemy fire as is the canister design. The design lends itself well to placement of smoke on the enemy by its residual effect of disruption upon impact.

(U) The disadvantages of the canister design is its reliability on the M84 series fuze which has a wide time variance inherent in its design. The best screening canister is of little value if it misses its intended target. Obviously, its use in rock or rocky soil is questionable.

The disadvantages of the submunition is its short duration of screen when compared with the canister. It is more complex in design and therefore less desireable to manufacture. At this time an additional problem exists as the flight stability tests of some of the potential tube configurations are not yet complete.

81 MM IR SMOKE MORTAR CARTRIDGE
(PAYLOAD CANNISTER)

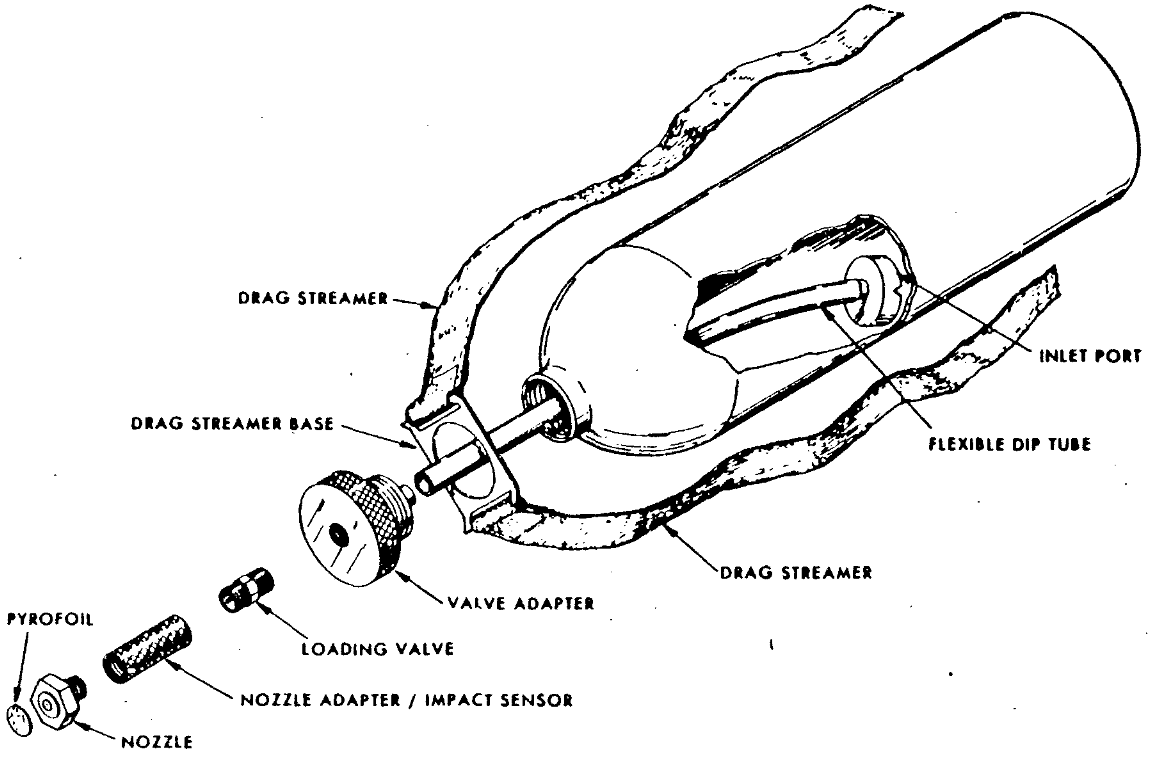


Figure 1. (U) Initial canister design.

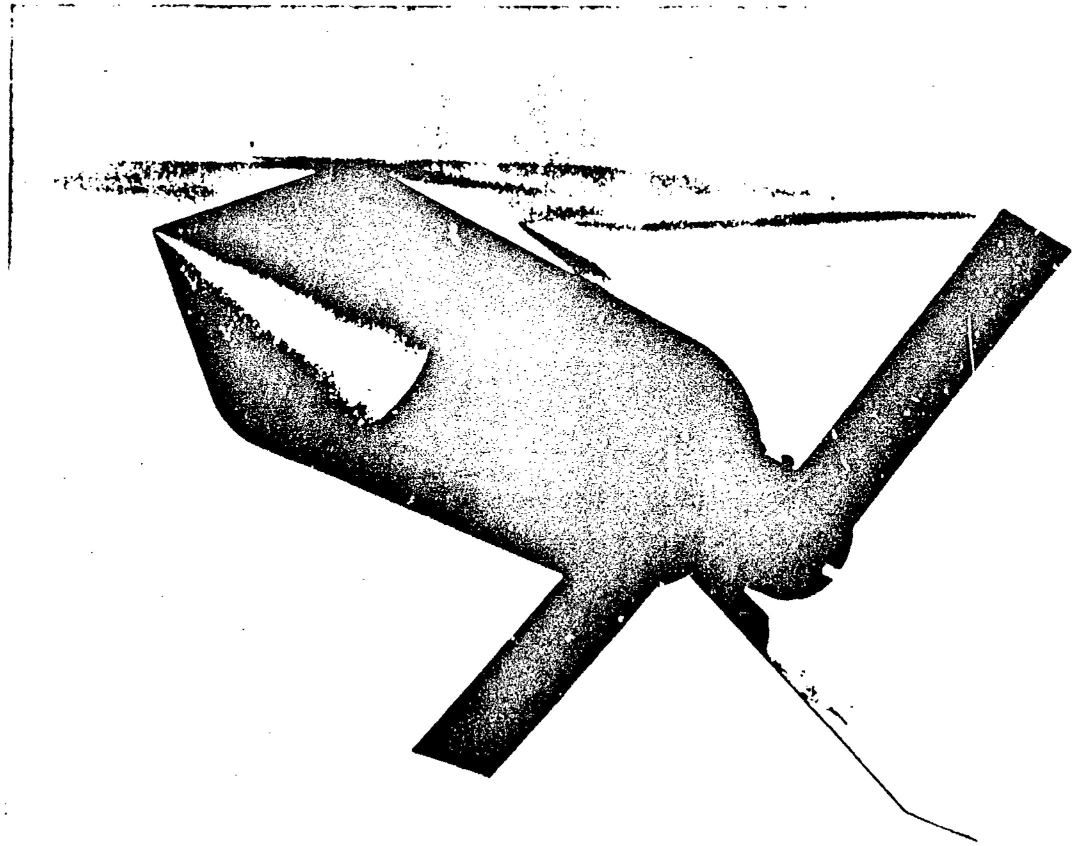
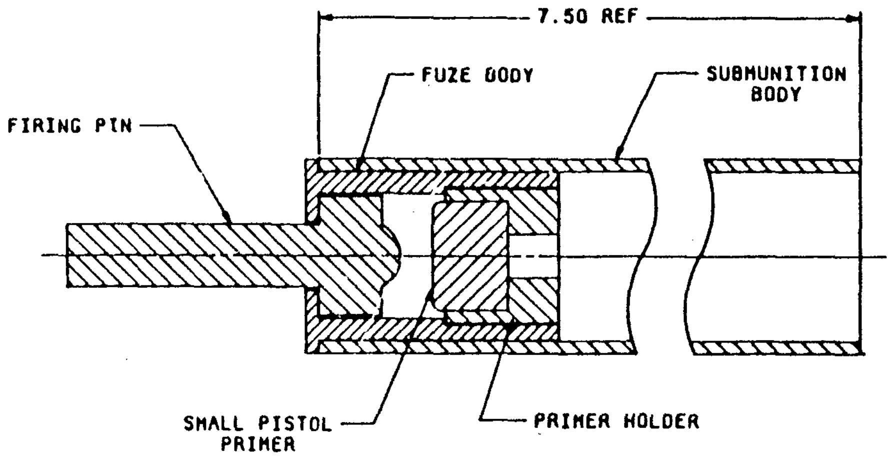
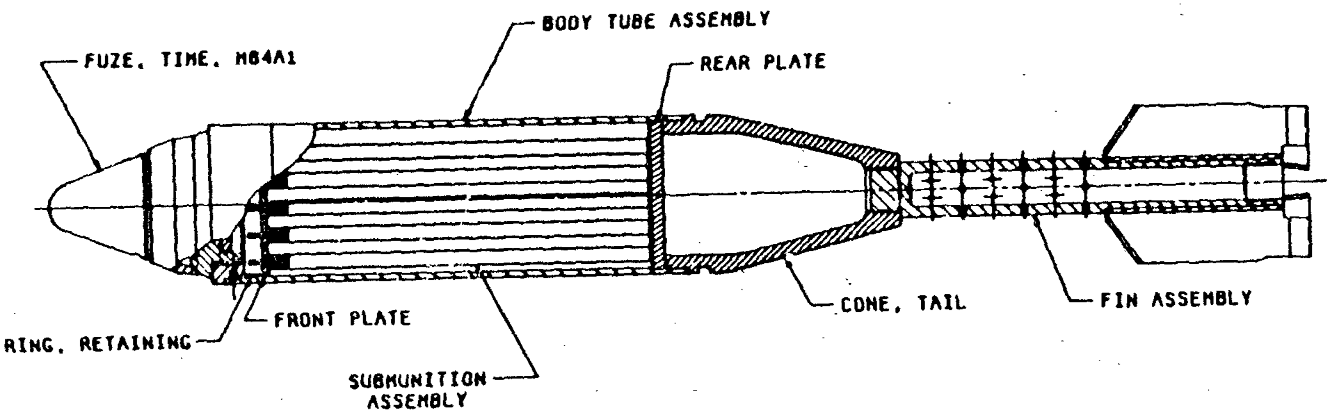


Figure 2. (U) Current canister configuration.



SUBMUNITION ASSEMBLY

Figure 3. (U) Single submunition body.



81MM IR SMOKE SUBMUNITION CONCEPT

Figure 4. (U) Complete mortar projectile.

1983 Annual Meeting
PYROTECHNICS AND EXPLOSIVES APPLICATIONS SECTION
of the
AMERICAN DEFENSE PREPAREDNESS ASSOCIATION

27, 28 and 29 September 1983

GENERAL DYNAMICS
Ft. Worth, Texas

TITLE Combined Effects Rockeye MK118 Bomblets

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ABSTRACT

A primary theme of Government personnel addressing ADPA meetings in recent years has been the affordability of new weapon systems. It has been suggested that the solution to affordability may be found in the improvement and increased capability of existing weapons at minimal costs. The Marquardt Company has addressed this challenge with the ROCKEYE MK118 bomblet with gratifying results.

The ROCKEYE bomblet was designed and has been produced (over 40 million) as a submunition with an anti-armor mission role. Two-hundred and forty-eight bomblets are packaged in the MK7 dispenser making up the weapon system designated the M20 ROCKEYE cluster munitions bomb. The MK20 is an air-launched free fall bomb which dispenses the MK118 bomblets over a target area approximately the size of a football field. The bomblet is activated upon impact and was primarily intended for a top attack on armored vehicles.

In an effort to extend useful life of the ROCKEYE at an affordable cost to the Government, Marquardt sponsored the design and demonstration of a MK118 bomblet with anti-armor, anti-material, and anti-personnel capabilities. These added capabilities were achieved with minimum changes to the basic bomblet and at a modest cost increase of 20% per bomblet.

Two simple modifications were made to the MK118 baseline bomblet to achieve the desired anti-personnel and material requirements. The I.D. of the bomblet was scored in a pre-determined pattern to achieve controlled fragmentation. The fragment dimensions and configuration were designed to enhance the velocity and penetration capabilities. An incendiary capability was added to the bomblet by a coating of zirconium alloy on the I.D. Both modifications were accomplished in a manner to preclude degradation of the bomblet anti-armor capability.

Arena testing of the combined effects bomblet at the Battelle Lab facility, confirmed the increased capabilities of the bomblet. The anti-armor capability was unchanged. The controlled fragmentation produced penetration of 1/4" steel. The incendiary capability was demonstrated by the ignition and sustained combustion of #2 diesel fuel. This paper will present a description of the design modifications, arena tests, and the test results.

ELECTROSTATIC AND ELECTROMAGNETIC RESISTANT BLASTING CAPS, SQUIBS, AND CARTRIDGES

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ABSTRACT (U)

1. (U) INTRODUCTION

(U) This is the final report concerning the development of a new family of electromagnetic and electrostatic resistant blasting caps, igniters, cartridges, and firing line filters. This report will cover the electromagnetic attenuation, the electrostatic, qualification testing, documentation and nomenclature, and final status and outlook for use of the new concept.

2. (U) ELECTROMAGNETIC ATTENUATION

(U) Each of the devices makes use of a new ferrite, MN-67, that was introduced shortly before this project started approximately five years ago. What makes MN-67 different from other ferrites was that it has significant attenuation at 1 megahertz. Previous ferrites never had significant RF attenuation at this low a frequency. Attenuation at the upper and of the spectrum, the radar frequencies, was not a significant problem with the majority of the ferrites.

(U) Previous attemps to use ferrites made use of beads with either one or two holes. The ferrite beads were slipped over the twin leads to the bridgewire. The bead approach had several short comings. Generally 3 to 5 beads were required to get the level of attenuation desired. Since the beads had to be placed immediately next to the bridgewire and sealed to prevent Radio Frequency (RF) leakage around the beads, each device became rather bulky. In addition 5 ferrite beads generally were about expensive as the device itself. Assembly and sealing added to the cost. The further the bead concept had resonant frequencies instead of broadband protection across the electromagnetic frequencies desired. Fixed external capaciters had to be added to obtain the broadband protection. This added to the bulk and cost. Another drawback was that the beads when stacked in series were not as effective as the sum of the individual beads. The point of diminishing retainers was reached when about 5 beads were stacked in series. Stacked and sealed ferrite bead attenuator blasting caps were estimated to cost approximately $20 per unit when the unprotected cap was costing less than $1 each. The combination of expense and large size resulted in termination of previous efforts.

(U) The new approach reported by this paper makes use of MN-67 manufactured in the form of a multihole choke. The parellel windings of the leads apparently provide the capacitive effect, since no external fixed capacitors were required. Winding each lead through the choke 3 times (1 1/2 turns) provided the equivalent attenuation equal to or greater than 5 conventional beads. MN-67 is a dielectric insulator and therefore the bare wire leads could be wound through the choke without electrical insulation. The dielectric property of the choke greatly reduced the size and expense of the electromagnetic attenuator. Finer wires (without insulation) allowed smaller holes in the choke and the smaller hole pattern allowed the choke to be build within the inside diameter of the 25 caliber blasting cap.

(U) The MN-67 attenuates any stray electromagnetic energy traveling in the leads and converts it to heat. That generated heat must be transfered out of the device. Otherwise, either the sensitive bridge wire mix or one of the other explosive components in the blasting cap will automatically ignite due to the heat build up. The physical properties of the MN-67 choke are strong enough that when pressed into the conventional blasting cap outer case, it deforms the case slightly making an efficient seal and provides a good conductive heat path to transfer heat to the metal outer case. The second problem of isolating the hot choke from the heat sensitive explosive components was solved by using a phenolic spacer between the choke and the phenolic plug. During qualification testing at the NSWC Dahlgren the choke got hot enough on one over test that the krayton seal melted and extruded (an estimated 450° F) without the melting on the bridgewire setting 15° above ambient temperature. The design selected appears adequate to meet the environments expected.

(U) By using the choke design and keeping the leads and bridge wire resistance the same, the new protected cap (fig 1) is compatible with all of the existing blasting machines and firing lines in the inventory. No expensive changeover of inventory equipment is required. No expensive special encoders or non-electric firing devices are required in order to get an acceptable level of attenuation. The safety release provided by NSWC Dahlgren stated that the devices are safe to use in any electromagnetic environment where it is safe for the operator to work (Ref 1).

3. (U) ELECTROSTATIC MITIGATION

(U) Stray electrostatic energy can cause inadvertant firing of unprotected devices just as stray electromagnetic radiation can. The designer must take into account both pin to pin energy as well as pin to case. This statement is true for both elecostatic and electromagnetic cases. The electrostatic bleeding device must not break down at voltages that are too low. Other wise the bridgewire cannot be fired with conventional blasting machines. A breakdown voltage of approximately 800 volts was established as high reliability firing criteria while still maintaining the desired degree of safety. It was further decided that the electrostatic device should be capable of discharging at least 60.000 electrostatic volts without caustrophic breakdown.

(U) The electrostatic problem was given equal priority with the electromagnet because stray electrostatic build up will increase significantly when an Armed Forces personnel wear issued permanent press working uniforms. The previous issue (cotton) uniform will no longer be available for personnel handling explosive devices. It is mandatory that electrostatic protection be provided all sensitive explosive devices.

(U) After extensive searching, it was determined that the Hercules printed metal pattern on Mylar tape provided the lowest cost (1/4¢/unit), highest reliability, and maximum compatibility with concepts proposed forth high speed automated production. That device was used throughout the development and testing program.

4. (U) COMMALITY OF DESIGN

(U) The program was extremely constrained from a funding viewpoint. In order to convert all of the EOD tools over to electromagnetic and electrostatic resistant davices, it was necessary to make use of as many of the same components as practical. To make a squip that can be used bare (to start EOD burning operations) or confirmed (to ignite EOD burnout torches) it was decided to make use of all of the same hardware as the blasting cap. The explosive in the blasting cap was replaced with a hollow cylinder of magnesium-teflon-viton igniter composition. The unconfined squib fires for almost one second making this one of the few squibs that will ignite diesel fuel without help from other combustible material.

(U) Figure 2 shows the design with a threaded outer casing. The casing provides a hexogonal head for tightened with standard spark resistant tools or can be hand tightened if the outsied case is made from one inch aeragonal barsteck. The threads match any threads in existing EOD tools. The small diameter of the squib made this approach possible.

(U) The commonality of design allowed savings in the time and cost of the safety testing at NSWC Dahlgren. After the blasting cap was vigorously tested under all conditions and operating areas, the squib was tested with a smaller number of tests to verify that there was no measurable difference between the blasting cap and squib.

(U) Fig 3 shows a firing line filter that was build around the same MN-67 choke body. This filter provides a significant cost savings over the conventional design. Both the conventional filter and the ferrite filter were approved for EOD use.

(U) Fig 4 show the RF and Electrostatic Resistant cartridge that raplaced the earlier unprotected design.

(U) Fig 5 shows a sectioned view of the firing line filter in the breech cap of an EOD dearmer tool. The spring loaded firing pin makes contact with the MK 14 ignition element. When placed inside the dearmer or the ITROD torch the cartridge is sealed away from stray RF and only the filtered firing signal reaches the cartridge.

5. (U) QUALIFICATION TESTING

(U) The design for each device was developed in iterative fashion. Early in the program alternate concepts were evaluated. The original head dissipation mechanism was the use of paraffin. The melting of the paraffin used the latent head of fusion to absorb some of the energy and the melted paraffin was then used as a liquid heat transfer medium to help transfer heat to the case to be dissipated to the surrounding environment. The use of paraffin proved to be expensive and required more space than desired. The design eventually evolved into the one described earlier.

(U) Other early concepts investigated were the trade offs between beeds and chokes. A single choke was eventually selected on the basis of space requirements, performance and cost. A six hole choke, 1.5 turns on each of two leads was determined to be the most cost effective design.

(U) All of the electromagnetic design selection and qualification testing was done at Franklin Institute. They publiished one report (Ref 2) that contained all the data. Care must be used in extracting the data. Early concepts were tested but not incorporated in the final design. Trade off testing was done with color coded hardware that looked identical. The color coding was not provided to Franklin Institute so it is not incorporated in the report.

(U) The early electrostatic testing was also done at Franklin Institute. After the prototype design was selected and units built at Hercules inc, Port Ewan, New York plant testing was also accomplished at that facility. The prototype units were tested against the M-6 qualification procedures called out in MIL-C-45468C the specification for the M-6 blasting cap.

(U) Testing was also done at the Naval Explosive Ordnance Disposal Technology Center, Indian Head, MD. These included functioning at simulated depths of 620 feet and functionality of the design using existing blasting machines and firing procedures. A lilmited number of tests were conducted to demonstrate compatibility with existing EOD tools that use the M-6 blasting cap as the initiation device.

(U) The majority of the testing effort was concentrated on getting Safety Certification of the blasting cap by NEWC Dahlgren. A test plan was jointly prepared to evaluate the proposed new design when tested using current EOD procedures on the NSWC standard test grid with RF transmitters from 1 megahertz through x-band radars (ref 3). The tests were conducted with EOD personnel laying out the firing cables, conducting normal checkout procedures, and hooking up the new devices. The RF power levels were so high at some test conditions that arcs were visible on the firing line and leather gloves were required to make and break electrical hook-ups. No inadvertant firing occurred. No induced currents above 15% of the maximum no-fire current were observed under any condition (ref 4). This was the first blasting cap to ever receive certification for use in a high RD environment.

3. (U) DOCUMENTATION

(U) Following the successful completion of all the testing leading toward qualification, a design disclosure package was put together for each one of the items. Table 1 shows the summary of the documentation package.

Item	Top Drawing	Specification Identified
Blasting Cap	53711-5206524	WS-21888
Squib	53711-5761601	WS-21888
Firing Line Filter		

5. (U) WEAPON SYSTEM EXPLOSIVE REVIEW BOARD (WSESRB) REVIEW

(U) The total package of test results, documentation and reports generated during the development were forwarded to the WSESRB. After careful staff study and verification of critical design questions with the appropriate technical personnel, the WSESRB recommend approval for service use on 24 Jun 82 (Ref 5).

7. (U) INTEGRATING THE DEVICES INTO THE INVENTION

(U) On 13 Jul 82 official nomenclature was assigned to the devices to differentiate them from the non-resistant devices. The nomenclature assigned was as follows:

Cap, Electric Blasting; Mark 11 Mod 0

Squib, Electric Blasting; Mark 20 Mod 0

8. (U) CONCLUSTION

(U) The first low cost compact RF and electrostatic resistant explosive devices have been developed and introduced into the inventory. Each device was designed for high volume production in order to get the costs as low as practical for these high use items. These devices were made possible by use of a single compact MN-67 ferrite choke and a conductive printed circuit tape electrostatic shunt. The R&D task at the Naval Explosive Ordance Disposal Technology Center is now complete. All EOD tools requiring increased safety protection have been modified or will shortly incorporate these devices.

(U) This technology is now being made availabe to all of DOD to determine if there are other applications for the combination of devices. The technology has been revealed in the recently issued US Patent (Ref 7). Other applications have been proposed. Improvement patent applications have been filed and widening the application into other devices has been proposed. It is proposed that other segments of DOD investigate the technology to determine if this simple, low cost combination can solve safety problems on other applications.

REF 1. Naval Surface Weapons Center, Dahlgen, VA, letter dated 16 Oct 81, Subject: XM6-1 Blasting Cap, Squibs, and Modified Cartridge; HERO Tests of

REF 2. Franklin Research center, Phila, PA, Technical Report F-C 5067, Subject: RF and Electrostatic Testing of Detonators by Joseph Heffran, Dec 79.

REF 3. Naval Surface Weapons Center, Dohlgren, VA, Subject: HERO Test Plan for the XM6-1 Blasting Cap, Squib and Modified 50 Cal Cartridges.

REF 4. Naval Surface Weapons, Dehlgren, VA, HERO Test Results Summary for the XM6-1 Blasting Cap, Squib and Modified 50 Caliber Cartridges.

REF 5. Naval Sea Systems Command, Washington, DC, letter of 24 Jun 82, Subject: Weapon System Explosives Safety Board Meeting on the Electric Blasting Cap, Electric 500 Cal Blank Cartridge, and Electric Squib.

REF 6. Naval Explosive Ordnance Disposal Technical Center MTAB letter 113-82 15 Oct 82, Subject: Radio Frequency and Electrostatic Resistant Initiated Devices.

REF 7. US Patent 4,378,910 Electromagnetic and Electrostatic Insensitive Blasting Caps, Squibs and Detonators, Paul W. Procter and Robert L. Dow.

The Use Of High Pressure Water Jets To Wash Out Explosives

by

David A. Summers, Paul E. Worsey
C. D. Robinson & J. E. Short

Introduction

In 1982 the Rock Mechanics and Explosives Research Center of the University of Missouri-Rolla undertook a program of research for the Naval Weapons Support Center in Crane, Indiana. The purpose of the research was to investigate the potential ignition hazards that would be associated with the use of high pressure water for washing out the explosive from existing military hardware. In the initial phases of this work a series of tests was carried out examining the results of firing water jets at samples of the explosive. Test requirements were to look at pump pressures of up to 25,000 psi and flow rates of up to 20 gpm. This work was carried out in three stages. The equipment used, the procedures involved and the reason for them are the subject of this paper.

Initial Equipment Layout

In order to achieve flow rates of 20 gpm (80 litres/min) at 25,000 psi (175 MPa), it was necessary that we use two of the high pressure pumps available at the Research Center. These are an Aquadyne*, 150 hp triplex pump, such as is conventionally used for cleaning, and a Flow Industries* intensifier, also rated at 150 hp. Each of these pumps has the capacity of putting out 10 gallons/minute when configured to deliver water at a pressure of 25,000 psi. In order to protect the operators of the equipment from any risk during the course of the experimentation, these tests were carried out in a partially quarried section of the University Experimental Mine property. On this site a concrete bunker has been built in which small charges can be ignited for observation or demonstration purposes. This bunker has been built into the end wall of a small passage. This passage lies adjacent to a second intersecting drive, slightly wider and which connects to one of the mine roads. (Fig. 1) The two pumps used for this work were accordingly located in the second drive, so that the intervening knoll would protect the pump operators during a test.

In earlier research long drill holes had been driven through the knoll and these provided a passageway for the high pressure line from the pump to the explosion bunker. To take advantage of this the Flow unit was set on the floor of the drive, adjacent to a drill hole, and arranged so that the high pressure flow of water passed into a stainless steel tube, that fed into the drill

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*The use of product names is for identification only, and does not indicate product endorsement by either the University of Missouri-Rolla or the Naval Weapons Support Center.

Enclosure (1)

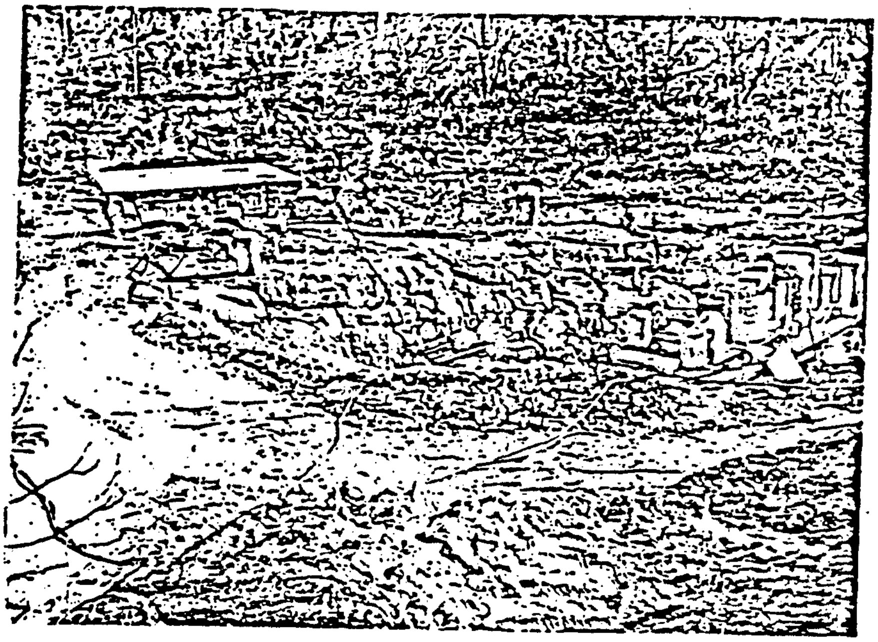
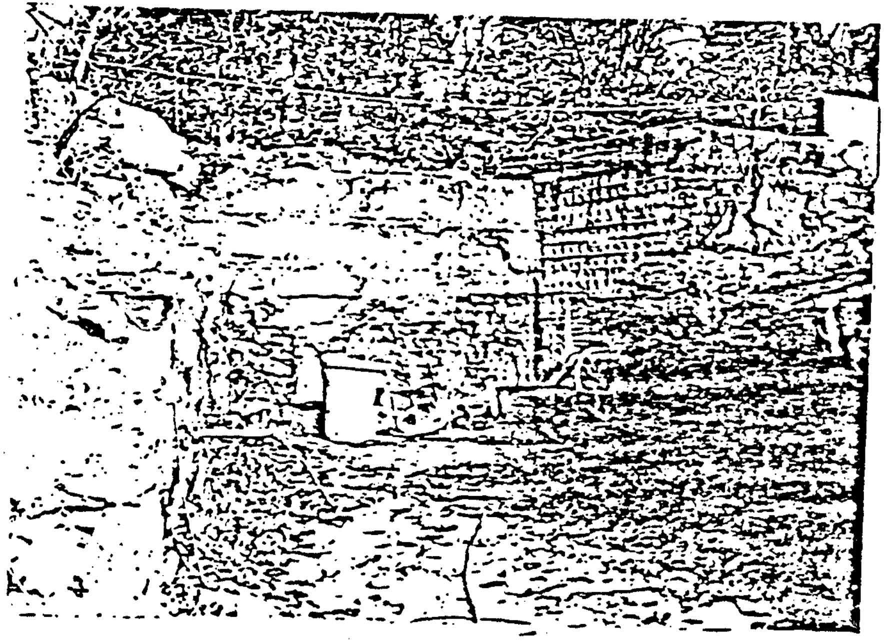


Figure 1. Experimental mine test site. The bunker is in the upper left.



Bunker at experimental mine.

hole. Within the drill hole the feed line was changed to a high pressure (32,000 psi burst) hose. Since this hose was only pressurized during a test, when all the operators were protected by the rock wall, this was considered to be a safe procedure. The use of hose permitted flexibility in manoeuvring the high pressure lance within the bunker, before and after each test.

The Aquadyne pump was mounted on the back of the Research Center trailer, and would have been expensive to remove. Because of the height of the knoll it was safe to leave the pump on this trailer, however.it was also easier to run the high pressure line from the pump over the knoll rather that through it. Again high pressure steel tubing was used to carry the water away from the operators position, and it was only in the vicinity of the bunker that the line was changed to the high pressure hose. Where the full flow of fluid was required for a test the two high pressure lines were joined together at a manifold approximately three feet back from the nozzle. This configuration was used to ensure that friction losses in the line were reduced to a minimum, while giving a length of 100 pipe diameters behind the nozzle to allow for some flow stabilization, before the water entered the nozzle.

For these tests commercially available tungsten carbide nozzles were used. This was not necessarily because we thought that these would produce the best jets of water. On the contrary researchers at Rolla, (Ref. 1), had shown that much better nozzles can be built. Rather these were used because they would be the most likely nozzles to be used were such a system to be built and used on a production basis.

Test Procedures

The tests were carried out in three stages. The first question to be answered was as to whether the explosives would be sensitive to the impact pressures likely to be generated on the target surface, during the initial microseconds of impact. It has been shown by investigators at the University of Cambridge, (Ref. 2), that pressures in excess of twice the water hammer pressure can be generated by the leading edge of a water jet slug on initial contact.

To determine if this should prove to be a risk the first tests were therefore set up to maximize the impact pressure on the target surface. In order to minimize the line losses in the delivery system, which was some 150 ft long, only 5 gpm of water was used in this test. Water was therefore only supplied from the Flow pump. A single 0.032 inch diameter nozzle was used on the end of the line for the test. In order to generate pulsations it was decided to externally chop the high pressure flow. This has the advantage of being a simpler operation to achieve than the commercial alternative of pulsation, (Ref. 3), and does not pose any risks of water hammering the line, which with the high pressures and low safety factors on the hose would have led to system failures. (It should be mentioned that

In later tests not described in this paper such a water hammering of the system did occur and led to the simultaneous rupturing of the high pressure hose in three places.)

In order to chop the flow, and at the same time to provide a shutter to prevent the water from hitting the sample until the right pressure had been reached, a circular shutter was constructed. The shutter was based on a previous concept developed by the senior author (Ref. 4) in which three slots are cut in a circular path around the shutter. The shutter has a central pivot and the edges of the slots are bevelled so that, once the shutter starts to spin, the impact of the water on the bevelled edge is sufficient to power the continued rotation of the shutter. (Fig. 2) The jet is, therefore, brought up to pressure on one of the blank segments of the shutter, the disc is then spun mechanically , and water can impact the target through the slots. The disc continues to spin, during the remainder of the test, driven by the water jet force and three slugs of water are generated for every rotation of the shutter.

Tests were carried out on eleven different military explosives using this technique, and with pump pressures of 25,000 psi. Calculations of the water hammer pressure generated by individual slug impacts indicated that the impact pressures would be in excess of 100,000 psi. In no case did the explosive noticeably react. (Fig. 3) In order to monitor the operation the test site was observed, during the test, by watching a television monitor. A remote television camera, with a good telephoto lens, was used to generate the picture. It should be mentioned that, in order to minimize the risk of flying debris, should the explosive react, each sample was set, in turn, in a special hole which had been drilled in the rock wall of the explosion bunker. In this manner, even should an explosion occur, the rock would contain the fragments of the metal casing.

Subsequent to the test the fragments of explosive were collected and a sample of the washout water was also taken and tested. In order to simplify this aspect of the program the floor of the bunker had been re-established by pouring a sloping bed of concrete which led into a cast sump, sized to hold all the water from an individual test. The water samples were sent to the Naval Weapons Center, China Lake, California, to be tested while the water from each test was kept in a plastic container until it had been approved for disposal.

Explosives are sensitive not only to the pressure of the impact, but also to the size of the area over which impact occurs. In tests of this type, some of the impact mechanisms might be so localized that while local explosive reaction might have occurred, the dimensional extent of the high pressure region was insufficient to permit growth of the reaction to a detectable size. In order to investigate this possibility the experiments

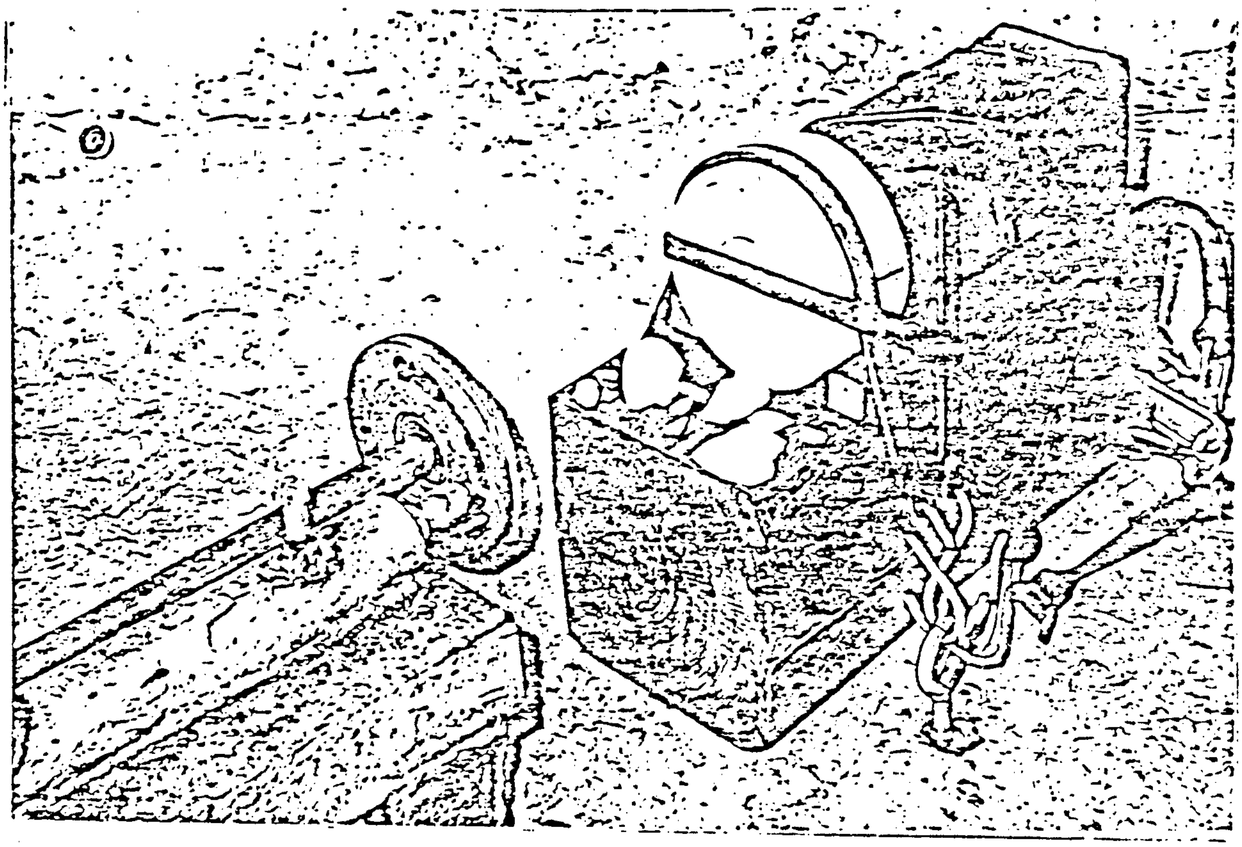


Figure 2. Circular shutter mounted to interupt jet flow from nozzle.

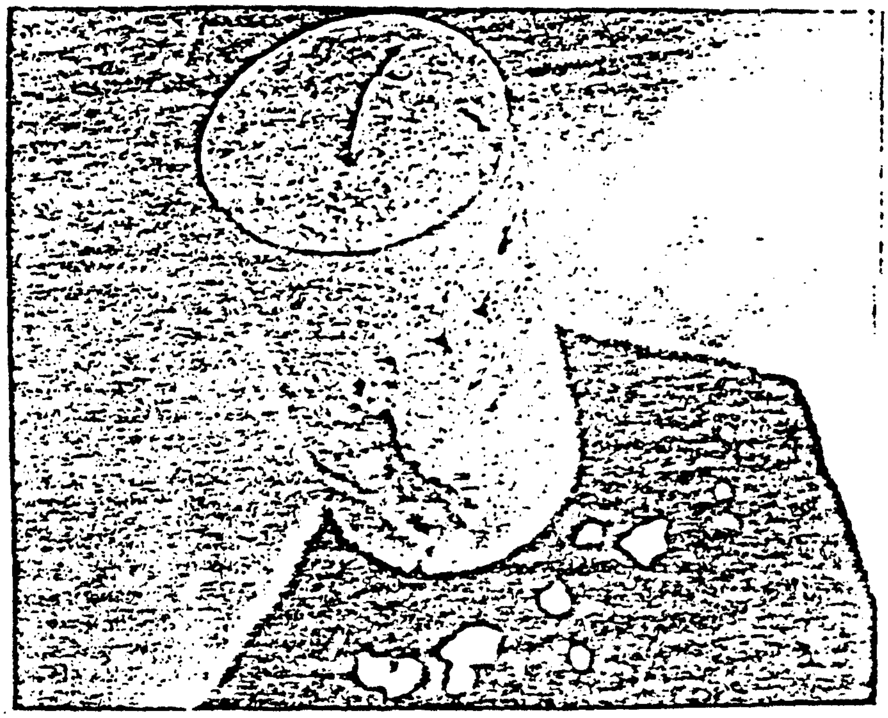


Figure 3. Post test sample of explosive showing pulsed jet holes.

were repeated at the same pump pressure, but with a larger (0.062 inch diameter) nozzle and thus a correspondingly larger flow rate of 20 gpm. (It should be mentioned that the charge diameters of the explosives used in this test were sufficient to permit growth to, and propagation of, high order detonation.)

In order to achieve the full flow at 25,000 psi both pumps were used. Some years ago when this possibility of pump combination had been brought up with the manufacturers, it had been recommended that the triplex pump be started and brought up to pressure first, followed by the Flow intensifier unit. This procedure was followed, with the two pumps being started and then, after the triplex had been brought up to pressure the intensifier was also brought up to pressure.

In order to protect the charge from the impact of the water during this time, a shutter was again placed between the nozzle and the charge. The initial design was, however, unworkable at the higher flow rate, since the force of friction due to the imbalance of forces on the disc stalled the shutter out. Accordingly, a single hinged shutter was set up. This device consisted of a plate attached to the bottom of the nozzle stand through a hinged connection. The plate was then located between the nozzle and the charge, and braced against the rock wall, to resist the force of the water. When both pumps had been brought up to full pressure, the bracing was removed by the pump operator, albeit, remotely through a wire connection. The force of the water was then sufficient to knock the shutter forward, out of the way, for the 10 second period of the test.

The test duration for this series was reduced from the 30 seconds taken for the first trials, with the pulsating jet. The first reason for this was that the major interest in this case was with the initial impact of the water on the explosive, since this would give the conditions most likely for reaction. A more prosaic reason was that, for virtually all the explosives tested in this part of the program, no explosive was left in the casing within one or two seconds of the initial impact. This shortening of the test period also reduced the amount of water which was collected after each test.

As was found with the first tests, using the pulsating water jet, no observable reaction was observed from any of the explosives during the period of washout. As in the earlier series a range of 11 different military explosives were tested in this part of the program. While a range of different responses were observed to the cleaning jet, some shattering, some breaking down into small pieces and some being removed as virtually single lumps of material, no indication of reaction on the fragments of explosive recovered could be observed either. The tests were, as previously, observed through a television camera and monitor at the time of test, and the signal was also recorded on videotape for later analysis.

A preliminary third phase of the experimentation looked at the ease with which the explosive could be washed from the container wall, at lower operating pressures. While the results obtained from that test series, in which the water jet was rotated over the sample, rather than merely impacting on it, are too few for a comprehensive report on their meaning at this time, several points can be made. Using the single smaller (0.032 inch diameter) jet it proved possible to wash out all but one of the explosives at pressures below 15,000 psi. It was, in all cases tried, possible to achieve a white metal finish on the casing for the explosive, where the jet was directed along the explosive/casing interface. The jet appeared capable of separating the explosive from the wall over a one inch distance along the wall, from a single pass over the surface.

One word of caution might perhaps be added to this report of research, which is still in progress. The tests were carried out with some care to minimize flow disturbances and friction losses in the line from the pump to the nozzle. In this type of work, where safety considerations will generally mandate such a large distance, high pressure losses can occur in the system, if such care is not taken. To give three specific examples of the precautions we have taken. Firstly, water was carried to the bunker in two separate lines to reduce friction losses in the lines. Secondly, a straight section of at least 100 pipe diameters existed, in the direction of ultimate flow, behind the nozzle body. Thirdly, when it became necessary to rotate the nozzle this was done by swiveling the feed pipe around in a gyratory fashion, by use of an encircling pipe, to which the tubing was pivotally connected. (Fig. 4) By this device, patented by one of our colleagues, (Ref. 5), it is possible to do away with the use of rotary couplings, and thereby save the pressure loss that would otherwise have been incurred in their use.

Acknowledgements

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The work could not have been carried out without the able assistance and advice of the Research Center staff, most particularly Mr. L. J. Tyler, Mr. J. Blaine and Mr. R. Fossey. It is our pleasure to record our appreciation for this effort.

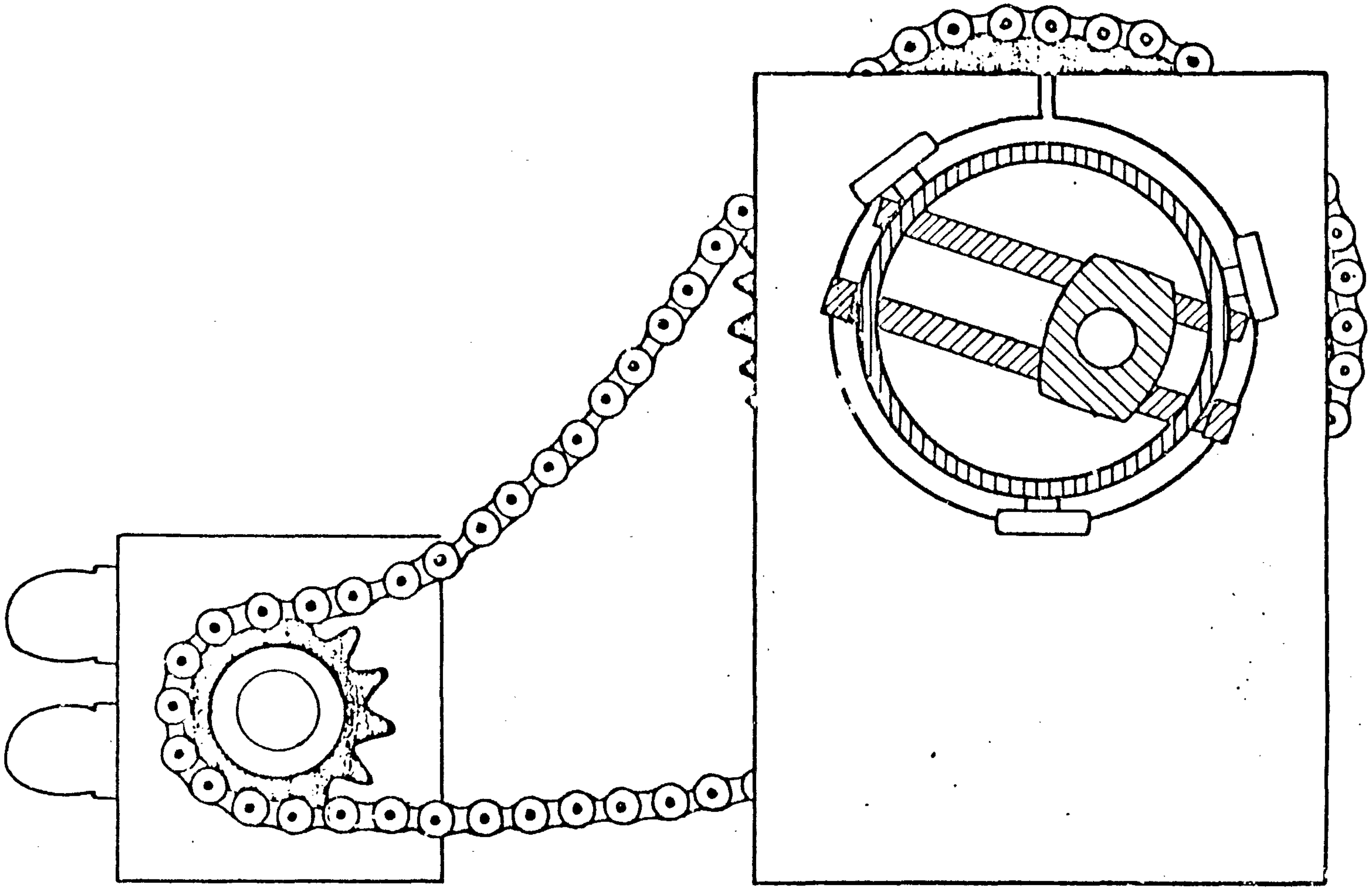

Figure 4. Front view of rotary drive mechanism for the water jet nozzle.

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A SCIENTIFIC METHOD FOR DETERMINING THE USEFUL LIFE OF EXPLOSIVE DEVICES IN AIRCRAFT

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Pyrotechnics and Explosives Application Section
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A SCIENTIFIC METHOD FOR DETERMINING THE USEFUL LIFE OF EXPLOSIVE DEVICES IN AIRCRAFT

1.0 INTRODUCTION

Every aerospace explosive device has a limited useful life because the organic chemical compounds (e.g., explosives, propellants, ignition materials, priming mixtures) contained in it deteriorate as a result of chemical reactions caused by heat. When this deterioration reaches a certain state, the device may no longer be capable of being fired or, if fired, may not function properly. The determination of the safe useful service life of a device has traditionally been based upon educated estimates and the results of testing of groups of devices removed at intervals from operational aircraft. This traditional method must necessarily involve very conservative initial estimates and requires many years of testing to lead to the desired values. The F-16 System Program Office has recently authorized General Dynamics to undertake a three-phase program to make an early determination, in a scientific manner, of the true useful service life of every contractor-furnished explosive device in the F-16 crew-escape-initiation system. This program, which could be applied to any types of explosive devices in any aircraft, is to be performed in three phases:

I. The experimental determination of the true thermal environment of each of the explosive devices under worst-case operational conditions

II. The performance of accelerated-service-life tests of each type of device under the environmental conditions established during Phase I

III. The performance of conventional surveillance testing

This paper first discusses the factors that govern the useful life of aircraft explosive devices. Then it outlines briefly the traditional method of determining service life and some of the inadequacies of this method. Finally, it describes the scientific method being pursued by General Dynamics and details its application to F-16 crew-escape explosive devices.

2.0 FACTORS THAT GOVERN THE USEFUL LIFE OF THE TYPICAL AIRCRAFT EXPLOSIVE DEVICE

Most, if not all, modern aircraft explosive devices (catapults, thrusters, rocket motors, initiators, cutters, energy-transfer lines, explosive bolts, etc.) are sealed against the entrance of moisture into primers, ignition materials, propellants, and explosives. Most of them are so constructed that they are not damaged by the vibration and shock that they experience during aircraft operations. They are protected against corrosion. The only detrimental environmental condition against which they cannot be protected is elevated temperature. Therefore, the useful life of these devices is governed by the length of time they are exposed to higher-than-normal temperatures and the rate of degradation of the various reactive materials contained in them at these temperatures. No explosive device has an inherent service life. Its true service life will differ in every application, being much shorter under severe environmental conditions than under mild environmental conditions.

Theoretically every organic material undergoes some deterioration at any temperature above absolute zero. Experience has shown, however, that most modern priming compounds, ignition materials, propellants, and explosives deteriorate very slowly at the usual storage temperatures ($<90^{\circ}F$), often showing no significant changes in any of the commonly measured properties (burning rate, detonation velocity, ease of ignition, elongation, etc.) after storage for 30 or 40 years. The time at which these properties begin to be degraded at a rate that is of concern to their users is the time when they are out of controlled storage and are subjected to the high temperatures often experienced in aircraft operations.

Most of the explosive devices used on today's military aircraft are components of the crew-escape system and the weapon-release-and-ejection systems. The devices in the weapon systems are usually located in weapon bays or on underwing racks and are, therefore, protected from very high temperatures. On the other hand, most of the escape-system devices in fighter aircraft are contained in the cockpit. When the aircraft are parked on the ramp with the canopy closed on hot days the temperature of the air under the transparency can frequently exceed 200°F. This report is concerned primarily with cockpit-mounted crew-escape-system explosive devices.

3.0 THE TRADITIONAL METHOD OF DETERMINING THE SERVICE LIFE OF AN AIRCRAFT EXPLOSIVE DEVICE

3.1 Definitions of Terms

The useful life of explosive devices used in aircraft is usually described by three terms:

a. Total life (called "shelf life" in Air Force publications). The interval between the date of manufacture of an explosive device and the time at which the device must be removed from the aircraft in which it was installed.

b. Service life. The period of time during which an explosive device may be safely used on an aircraft. Sometimes the beginning of this period is taken to be the date of the installation of the device on the aircraft. In the case of the F-16 the beginning is the day on which the aircraft is rolled out of the factory. Normally the first flight of the aircraft takes place a few days after its rollout; therefore, service life is, effectively, the time during which the explosive devices are exposed to the temperature fluctuations that occur during aircraft operations.

c. Storage life. The storage life of an explosive device is the length of time during which the device may be kept in a controlled (moderate temperature) environment (such as an ammunition magazine or an airconditioned building) before its service life begins. It is the difference between total (shelf) life and service life. The storage life of a device can be extended beyond the specified limit provided that the service life of the device is reduced by the same amount.

Throughout this document the following terms are used:

a. Explosive device. Any device that contains primers, ignition material, propellants, explosives, or similar materials. Typical explosive devices used in aircraft are catapults, thrusters, initiators, explosive bolts, SMDC lines, and cutters.

b. Reactive materials. Primers, ignition materials, propellants, explosives, and any other materials that react to provide heat, gas, smoke, shock waves, etc.

3.2 The Traditional Method

The traditional approach to the determination of the service life of each aircraft explosive device has been to

a. Estimate its service life at the time of its introduction into operational usage.

b. Remove a few devices at intervals from operational aircraft and test fire them.

c. Compare the results of the tests with the results of acceptance tests of newly manufactured devices.

d. Extend the service life by a small amount (typically six to twelve months) if the test results show no evidence that the performance of the removed devices differs significantly from the performance of newly manufactured devices.

This process is continued for each type of explosive device as long as the device remains in service or until substantial evidence of deterioration is discovered. Table I illustrates the results of conventional surveillance testing on the determination of the service life of four widely used explosive devices, the M27, M28, M53, and M99 initiators.

3.3 The Inadequacies of the Traditional Method

The traditional approach to service life determination is inadequate for two important reasons:

a. A very long time is needed to arrive at the true service life of an explosive device. The slowness of the process is illustrated by the fact, as shown in Table I, that sixteen years (1966-1982) have been taken in determining that the M27, M28, M53, and M99 initiators have at least a ten-year service life in the "average" application. The full service life in the average application is still not known. Neither is the true service life known for worse-than-average conditions.

b. Deficiencies in the materials or the construction of explosive devices are often not discovered soon enough to permit prompt corrective action to be taken. A review of the literature discloses several instances in which explosive devices have performed improperly after having been in service for

Table I Service Life of M27, M28, M53, and M99 Initiators

The M27, M28, M53, and M99 initiators use the M91 impulse cartridge and are identical in all respects except for mounting provisions and method of actuation. All of these initiators were developed in 1961. The initial estimated service life was 36 months. Surveillance testing of various quantities of these devices (that had been removed from operational aircraft) began in 1966 and has continued. The dates at which decisions were made to increase the service life are tabulated below.

Date	Service Life Increased (months) From	To
June 1966	36	48
May 1968	48	60
July 1970	60	72
April 1973	72	84
April 1975	84	96
April 1980	96	102
January 1981	102	108
August 1982	108	120

The table above is a synthesis of a larger number of decisions concerning service life decisions relative to individual ones of the four initiators.

less time than permitted by the official service life. Analysis has shown, in these instances, that the environmental conditions to which the malfunctioning devices had been subjected were more severe than were the conditions to which the surveillance-test items had been subjected. The sudden discovery of such unanticipated problems has usually occurred after much hardware is already in service and redesign and replacement are difficult and time consuming.

4.0 THE SCIENTIFIC METHOD OF DETERMINING THE SERVICE LIFE OF AN EXPLOSIVE DEVICE

4.1 The Importance of Determining the True Service Life

The determination of the true service life of crew-escape-system explosive devices is important for two reasons:

a. If the official service life (the life listed in the -6 handbook) is much shorter than the true service life, excessive costs in labor and material will be incurred in unnecessary replacement of usable devices, and aircraft downtime will be greater than necessary

b. If the official service life is greater than the true service life, the devices may have deteriorated beyond the point of proper functioning and may either not fire or not perform properly when crew escape is attempted.

4.2 The Scientific Method

The scientific method of determining the true service life of aircraft explosive devices is based upon two premises:

a. The true service life of an aircraft-quality explosive device is determined solely by the thermal environment - i.e., time at elevated temperature (e.g., temperatures above 100°F) and the frequency of cycling between low and high temperature.

b. If the thermal environment can be determined - by prediction or measurement - the service life of a device can be determined in the laboratory in a short time by aging groups of devices for various periods of time at the predetermined elevated temperatures and then performance testing them.

In the case of crew-escape-system devices, the service-life-determination program consists of the following activities in sequence:

a. Determining, by actual temperature measurements in the using aircraft, what is the worst-case environment in which the device is expected to survive without a significant loss of capability to be fired or capability to function properly.

b. Developing, from the temperature measurements in the aircraft and from climatological data for the locations at which the aircraft are to be based, a temperature profile for worst-case operational conditions at these bases.

c. Devising an aging test which will, by the elimination of time at low temperature (e.g., temperatures below 100°F), permit the device to be subjected in a few months time to the worst-case environment that could be expected during a period of several years.

d. Performing the aging test on a quantity of the device, withdrawing and firing a partial quantity at intervals to evaluate the effects of increasing aging times on the performance of the device.

e. Establishing the service life for the device by comparison of the length of time during which the device successfully withstood the aging tests with the predetermined temperature profile.

f. Validating the chosen service life by performing conventional surveillance testing; that is, by periodically removing groups of the device from operational aircraft and testing them.

The first step - the measurement of the temperature of the device in its installed position in the aircraft - is crucial to the entire process of scientific service-life determination. A few measurements on one or two hot days in July or August (this has been past practice) will not suffice. Measurements must be made during several days of each month, with the canopy open and closed, over a several-month period (early spring to late summer or early summer to late fall) if the data are to be meaningful. All the measurements should be made at a place whose climate (especially solar radiation) is similar to the climate at the worst-case operational base. The following climatological data must be obtained continuously at a point close to the test aircraft simultaneously with the temperature measurements in the aircraft:

a. Solar radiation
b. Air temperature
c. Wind speed and direction
d. Relative humidity.

The application of the scientific method to the determination of the service life of the contractor-furnished crew-escape-initiation-system explosive devices is discussed in the following section of this document.

5.0 DETERMINING THE SERVICE LIFE OF F-16 ESCAPE SYSTEM EXPLOSIVE DEVICES

5.1 Initial Estimates

The service life of each of the contractor-furnished explosive devices in the crew-escape-initiation system in the F-16A (Figure 1) and F-16B (Figure 2) has been estimated from (a) the results of surveillance and temperature-aging tests of similar devices used in the F-111 crew escape system and (b) estimates of temperatures in the F-16 cockpit. The goals of the recently authorized service-life-determination program are to confirm these estimates (Table II) as quickly as possible and discover how much, if any, these service lives can be extended.

5.2 Making Temperature Measurements

The equipment for making measurements of the temperature of F-16 explosive devices consists of (a) the F-16A sled (which is an F-16A forward fuselage) mounted on a special support structure (Figure 3) and equipped with inert explosive devices and temperature sensors (Figure 4) and (b) an instrument package that:

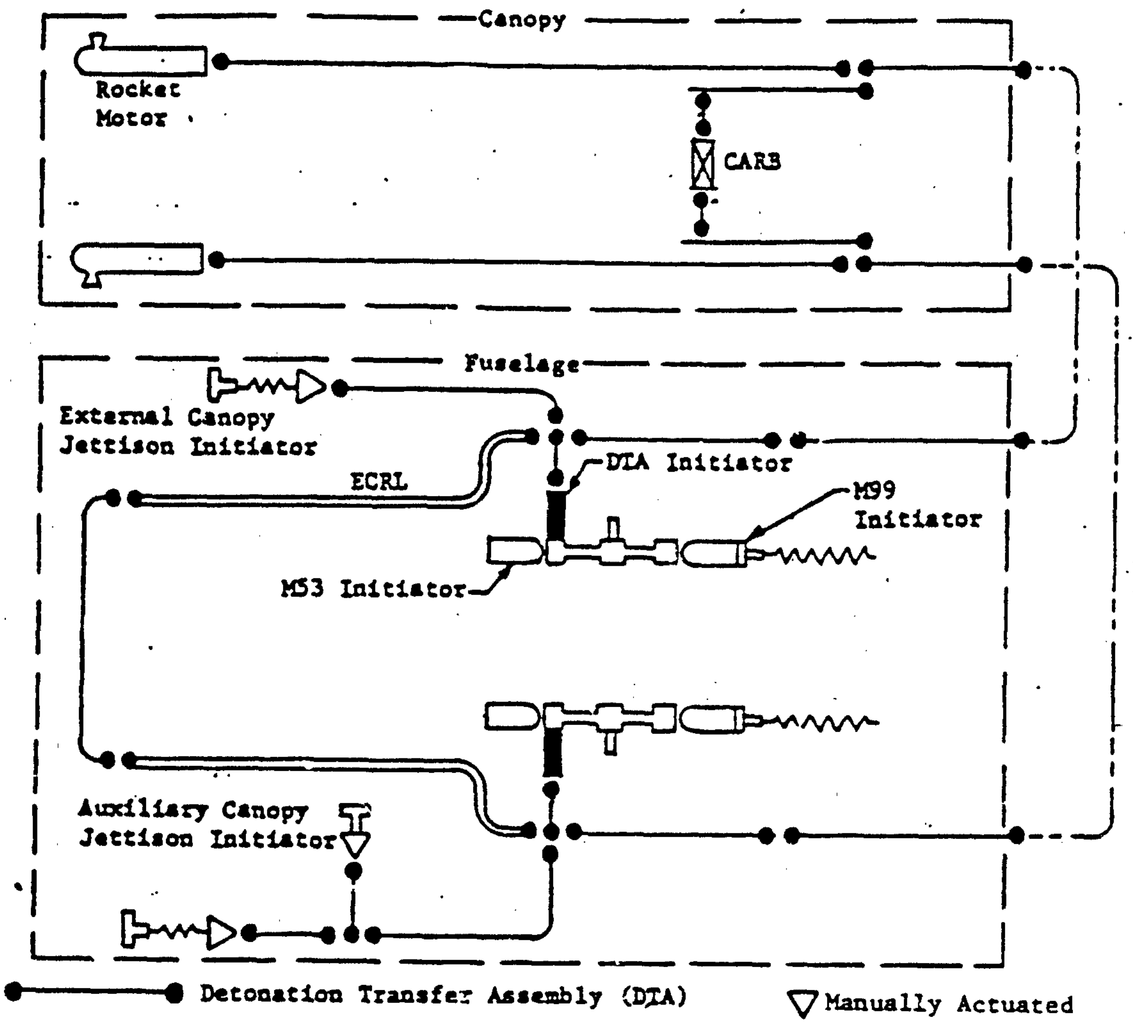
a. Continuously records the temperatures measured by the sensors in the sled.

b. Continuously measures and records environmental conditions (air temperature, solar radiation, wind speed, and wind direction) at cockpit level.

Measurements of relative humidity are obtained from other sources. The temperature measurements are being made continuously between approximately 9:00 AM and 4:00 PM on selected (clear) days with the sled parked on a concrete surface and oriented as listed in Table III.

5.3 Establishing Temperature Profiles

Climatological data for each airbase at which F-16s will be stationed will be obtained from the National Climate Center (for domestic bases) and other sources (for foreign bases). The "worst" local climate (the one with the highest temperature and solar radiation) will be selected from these data. Summaries of pertinent climatological factors (e.g., solar radiation and air temperature) will be prepared from the data for the selected airbase. Figures 5 and 6 are examples of such summaries.



▽ Manually Actuated DTA Initiator

▮ Gas Actuated DTA Initiator

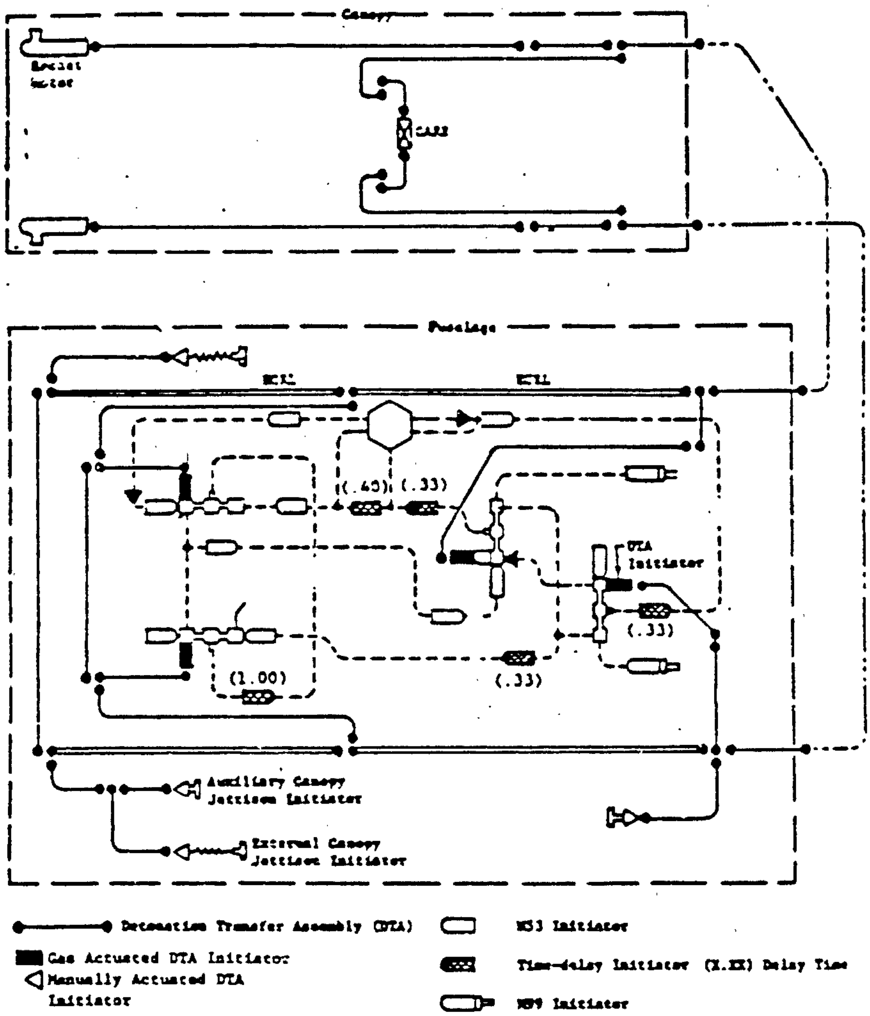
Government-furnished Devices

M53 Initiator (2)
M99 Initiator (2)

Contractor-furnished Devices

Canopy Remover Rocket Motor (2)
Emergency Canopy Release Line (ECRL) (2)
Detonation Transfer Assembly (DTA) (19)
Gas-Actuated DTA Initiator (2)
Manually Actuated DTA Initiator (3)
Canopy Actuator Release Bolt (CARB) (1)

Figure 1 Explosive Devices in F-16A Crew Escape Initiation System



Government-furnished Devices

M53 Initiator (10)
M99 Initiator (2)

Contractor-furnished Devices

Canopy Remover Rocket Motor (4)
Emergency Canopy Release Line (ECRL) (4)
Detonation Transfer Assembly (DTA) (27)
Gas-Actuated DTA Initiator (4)
Manually Actuated DTA Initiator (4)
Gas-Actuated Dual Delay Initiator (5)
Canopy Actuator Release Bolt (CARB) (1)

Figure 2 Explosive Devices in F-16B Crew Escape Initiation System

Table II Estimated Service Lives of Contractor-Furnished Explosive Devices in F-16A/B Crew Escape System

Item	Total Life (months)	Service Life (months)
16VK014-X Rocket Motor	72	36
16VK016-XXX ECRL	240	180
16VK018-X Gas Actuated Initiator	126	90
16VK019-X CARB	240	180
16VK020-X Dual Delay Initiator	96	60
16VK020-X Manually Actuated Initiator	126	90
16VK023-XXX DTA		
Type S and SS	240	180
Type F	90	30*
Type D	240	180
Type R	108	72
Type C	240	180
Type FC	240	180
Type ST	240	180

*This service life is based upon the flexure life of the device, not on the thermal stability of the explosive materials contained in it.

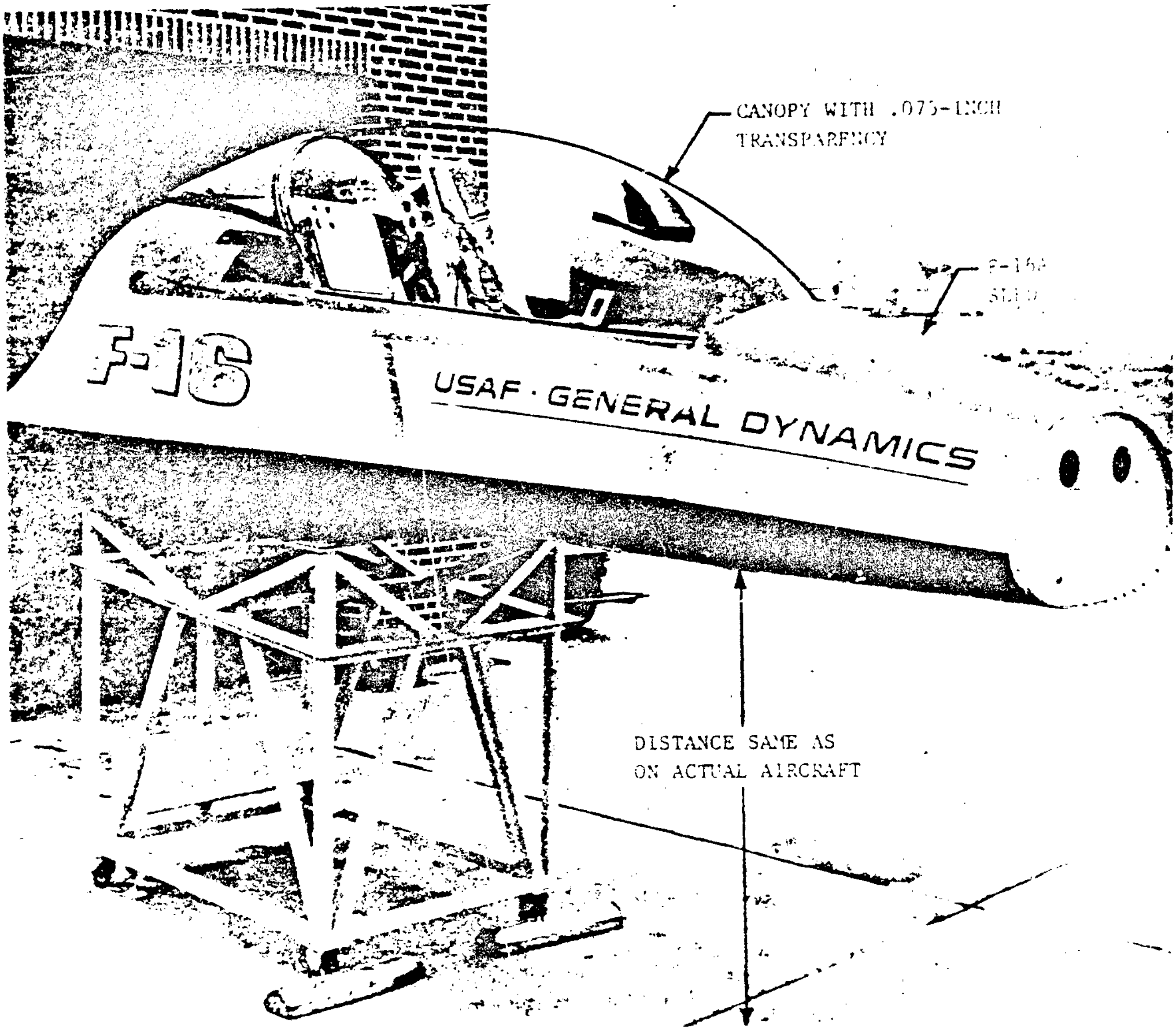
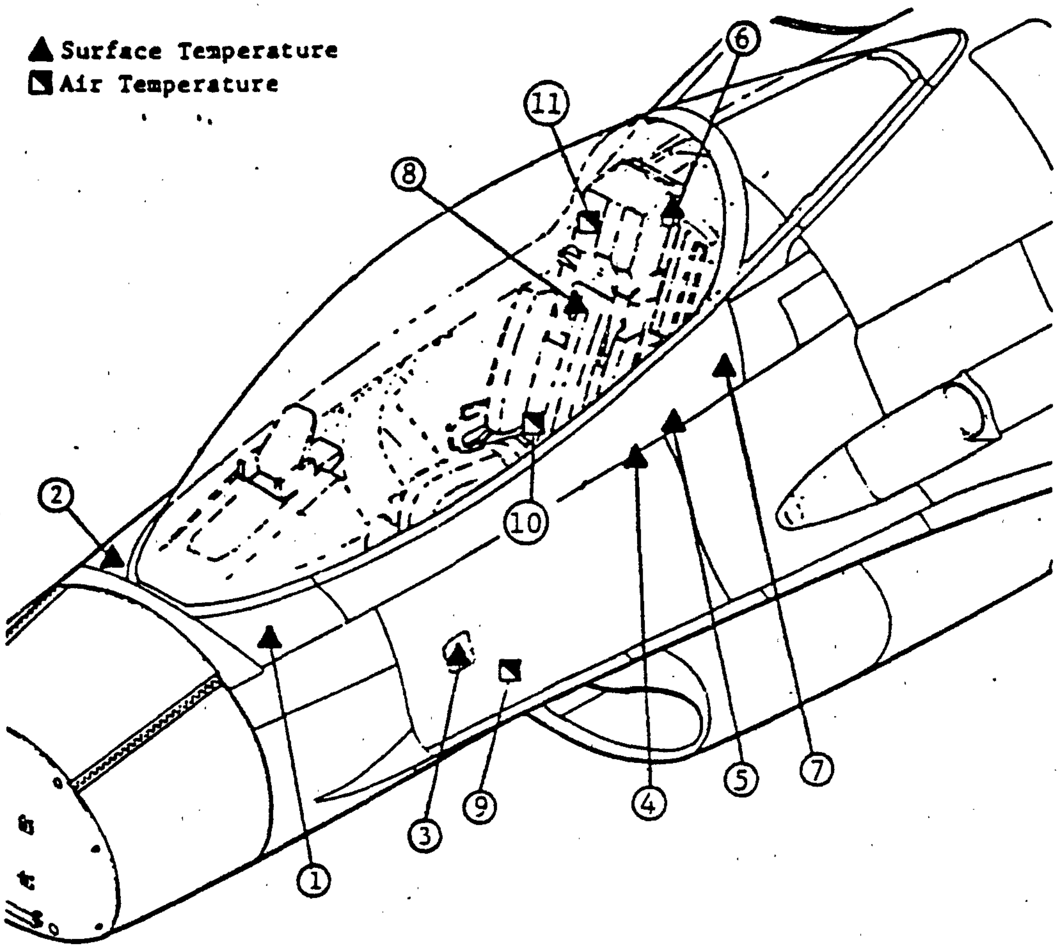


Figure 3 Vehicle Used for Temperature Measurements



Measure temperature at:

1. Surface of left-side canopy-remover rocket motor
2. Surface of right-side canopy-remover rocket motor
3. Surface of lower portion of left-side external canopy-jettison initiator.
4. Surface of ECRL on left side near aft end
5. Underside of canopy frame near aft end
6. Surface of canopy actuator release bolt (CARB)
7. Surface of canopy torque tube near outboard end
8. Surface of gas-actuated DTA initiator
9. One inch above cockpit floor at centerline of fuselage
10. At pilot waist level at aircraft centerline
11. At pilot head level at aircraft centerline

Figure 4 Locations for Temperature Sensors

Table III Plan for Temperature Measurements

Month	Quantity of Measuring Days	Canopy Position		Position of Sled		
		Open	Closed	Nose South	Nose North	Nose East
July	2		X	X		
	1	X		X		
	1		X		X	
	1		X			X
Aug.	2		X	X		
	1	X		X		
	1		X			X
Sept.	2		X	X		
	1	X		X		
	1		X		X	
	1		X			X
Oct.	2		X	X		
	1		X		X	
	1		X			X

NOTES:

1. Test days are to be days when the solar radiation is expected to be high (little haze and cloudiness).

2. The measurement period is to begin not later than 9:00 AM and end not earlier than 4:00 PM on each measuring day.

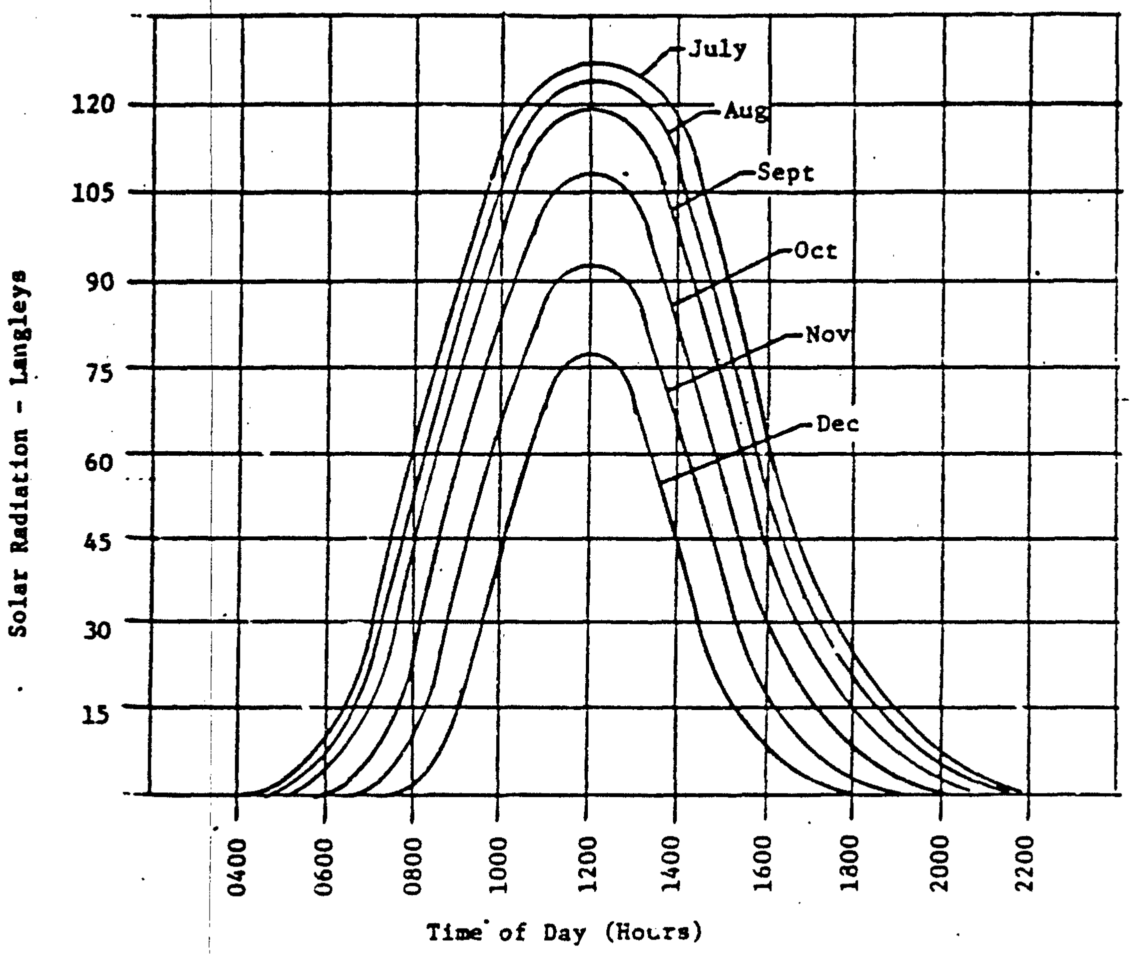


Figure 5 Mean Daily Solar Radiation for _______ AFB

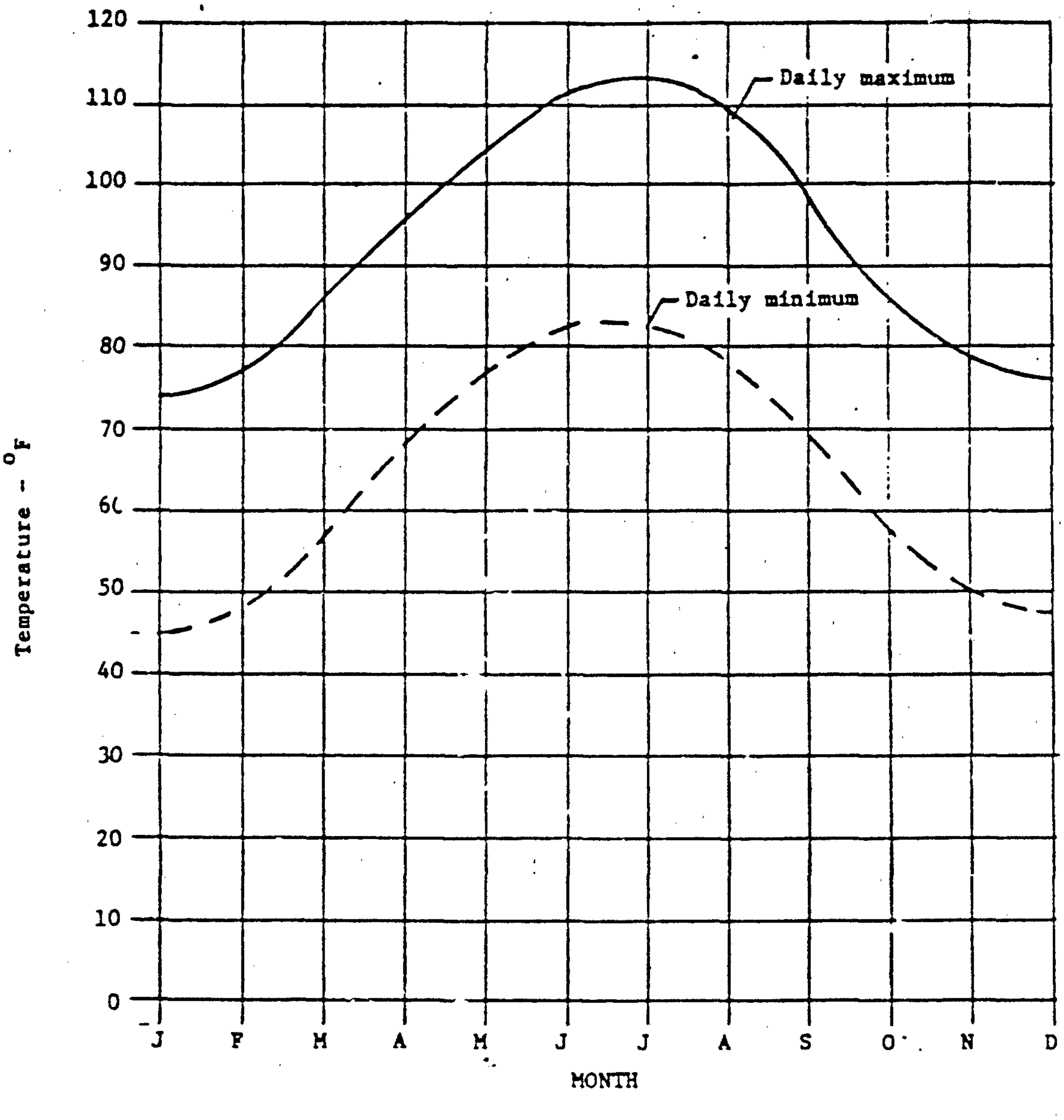


Figure 6 Maximum and Minimum Temperatures at
____________ AFB

Next, information will be obtained on the operational patterns for F-16 aircraft at the selected base, including such factors as:

a. Percentage of time aircraft is parked on pavement.

b. Percentage of time canopy is closed when aircraft is parked.

c. Flight hours per month.

Finally, a temperature profile will be developed for each explosive device for a typical F-16 that is operating from the worst-case airbase under worst-case conditions. This profile will be based upon the temperatures measured in the F-16A sled with suitable adjustments to account for the historical climatological data for the chosen airbase.

A hypothetical temperature profile for the 16VK018 initiator is presented in Table IV.

5.4 Temperature Aging Tests

A temperature-aging plan will be developed for each type explosive item. This plan will simulate, in a short calendar period, the effects of the degradation that will take place in the reactive materials in the device over a period of many years under actual aircraft operating conditions. The tests performed in accordance with this plan will permit an early determination to be made of the validity of the estimated service life for the device and of the possibility of increasing the service life.

The general plan for temperature aging may be most readily described by an example, Figure 7, which shows a proposed temperature cycle and a cycling plan for the 16VK018 initiator, describes the test procedure, and lists the conclusions to be drawn from the test results. The proposed temperature cycle, which is based upon the temperature profile data of Table IV, is formulated upon the assumption (which has both theoretical and historical support) that temperatures below 100°F may be safely neglected.

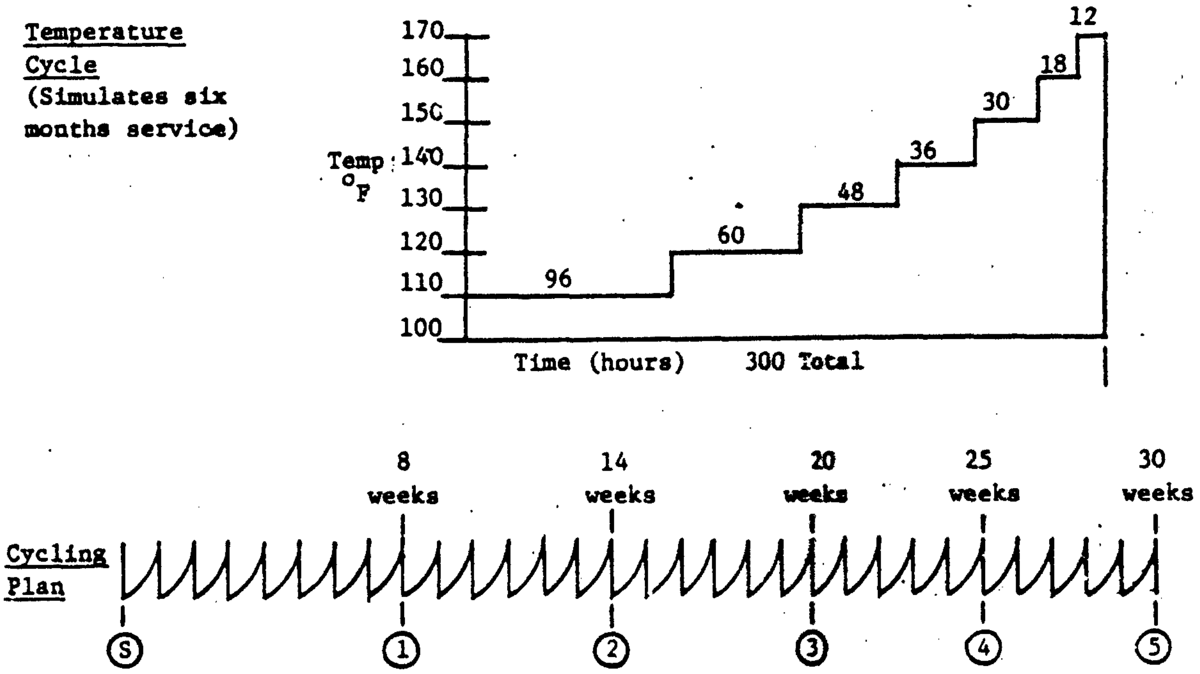
In this example each increment of temperature in the cycle is one-thirtieth of the estimated fifteen-year total in Table IV (e.g., 2880/30 hours at 120-130°F = 96 hours at 130°F); therefore, one cycle simulates the temperature aging expected during a six-month worst-case operational period. If the cycling is performed in a programmed temperature chamber that operates

Table IV Hypothetical Fifteen-Year Temperature Profile for 16VK018 Initiator Installed in F-16 Operating Out of ________ AFB

Temperature °F	Time at Temperature (Hours)		
	Aircraft in Flight	Aircraft on Ground	Total
170-180			
160-170		360	360
150-160		540	540
140-150		900	900
130-140		1,080	1,080
120-130		1,440	1,440
110-120	210	1,590	1,800
100-110	300	2,580	2,880
100	7,490	114,910	122,400
	8,000	123,400	131,400

Assumptions:

1. The aircraft will be operated through its life at ______ AFB.
2. The aircraft will always be parked in the open when not in flight or undergoing major maintenance.
3. The canopy will be closed during all or most of the day ____ percent of the time.



Test Procedure and Conclusions

Start test with 50 initiators. Withdraw 10 initiators at each indicated period. Test fire 5 of these initiators at -65°F and 5 at 200°F.

Ⓢ Start temperature cycling.

① End of eighth cycle (4.0 years simulated service)
Conclusion: Successful tests confirm 4 years of predicted service life.

② End of fourteenth cycle (7.0 years simulated service)
Conclusion: Successful tests confirm predicted 7-year service life.

③ End of twentieth cycle (10.0 years simulated service)
Conclusion: Successful tests permit extending service life to 10 years.

④ End of twenty-fifth cycle (12.5 years simulated service)
Conclusion: Successful tests permit extending service life to 12.5 years.

⑤ End of thirtieth cycle (15.0 years simulated service)
Conclusion: Successful tests permit extending service life to 15 years.

Figure 7 Hypothetical Plan for Aging Tests of 16VK018 Initiator around the clock (which has been the practice during temperature aging of the F-111 explosive devices), the predicted seven-year service life for the 16VK018 initiator can be simulated in 14 weeks. If significant degradation of initiator performance is discovered during testing at the end of the eighth cycle or the fourteenth cycle, the seven-year service life can be reduced. If no significant degradation is observed during the testing at the conclusion of the fourteenth cycle, the cycling will be continued, as shown in Figure 7, to demonstrate the suitability of the initiator for longer service.

General Dynamics will submit the proposed temperature-aging plan for each type explosive device to the Air Force for approval. Agreement will be reached before the testing begins on the interpretation of the test results and on the decision to be made at the conclusion of each increment of cycling and testing.

Fifty new explosive devices of each of the types listed in Table V will be utilized in the temperature-aging tests. Each type of device will be tested in the same manner as it is tested in lot-acceptance testing except that the cartridge for the dual-delay initiator will be tested in a special closed-bomb fixture. The results of the tests of each subgroup of each type of device will be compared with the results of the tests performed by the manufacturer of the device during the acceptance of the lot of devices from which the fifty devices were taken. Any differences will be recorded. Any decision to revise the estimated service life of a device will be based upon the results of the tests.

The service life of each type of F-16A/B explosive device that will not be tested can be established on the basis of the results of the tests of similar devices listed in Table V. For example, the type D DTA is representative in all essential respects to the types S, SS, F, and FC DTAs and to the canopy actuator release bolt (CARB) and the emergency canopy release line (ECRL).

5.5 Conventional Surveillance Tests

Conventional surveillance tests (see 3.2) will also be conducted. Such testing will serve to confirm the results of the accelerated service-life tests and to disclose problems that may arise from unanticipated conditions.

Table V Devices to be used in Aging Tests

1. 16VK014-5 (or -6) Canopy Remover Rocket Motor (with stab primer)
2. Type D DTA (16VK023-503)
3. Type R DTA (16VK023-701)
4. Type ST DTA (16VK023-721)
5. Explosive train used in 16VK018-1 (or 16VK022-1) DTA Initiator
6. Cartridge used in 16VK020-5 (or -6) Dual Delay Initiator

U S MPBMA

PYROTECHNIC SAFETY ENHANCEMENT PROGRAM

BY

STUART NEMIROFF
PROJECT MANAGER

SEPTEMBER 1983

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Mr. J. Hab - Clothing Designer

Ms. E. J. Noddin - Program Coordinator

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Mr. J. Matura - Munitions Application Section, Project Engineer

Mr. P. Spur - Munitions Application Section, Assistant to Project Engineer

INTRODUCTION

For some years, there has been a continuing incidence of injuries and deaths in the pyrotechnic industry. These incidences have occurred in both private industry and Government owned facilities. In Mar 80, a Pyrotechnic Safety Enhancement Program started to take form under the management of the US Army Munitions Production Base Modernization Agency (MPBMA), located in Building 171 at Picatinny Arsenal (or, as it became known, ARRADCOM, Dover; or, as it is now known, AMCCOM (D)), Dover, NJ. The program was and currently is managed by Mr. Stuart Nemiroff.

BACKGROUND

In Mar 80, information relating to pyrotechnic operations was requested from five Government facilities for the purpose of identifying needs in the areas of pyrotechnic safety. The facilities were:

1. Crane Army Ammunition Activity

   Type: Government-owned and Government-operated (GOGO)

   Location: Crane, IN

2. Lake City Army Ammunition Plant

   Type: Government-owned, contractor-operated (GOCO)

   Location: Independence, MO

3. Lone Star Army Ammunition Plant

   Type: GOCO

   Location: Texarkana, TX

4. Longhorn Army Ammunition Plant

   Type: GOCO

   Location: Marshall, TX

5. Pine Bluff Arsenal

   Type: GOGO

   Location: Pine Bluff, AR

Responses were too generalized to be of significant use. In Sep 80, a meeting was held at ARRCOM (Rock Island, IL) for the purpose of better defining areas of needed improvement in pyrotechnic manufacturing. At this meeting, a questionnaire was distributed (appendix A) to the respective facilities.

The information supplied was technically evaluated and discussed with each individual plant. Priorities were established and, by Jan 81, an overall Pyrotechnic Safety Enhancement Program was formalized.

The program was divided into three phases.

Phase I - Safety enchancement in this area involved furnishing the respective facilities with small amounts of funding to make immediate type corrections to their respective processing areas, such as additional safety shields, improved functioning doors, etc.

Phase II - This involved areas such as installation of new mixers to replace worn or damaged mixers, installation of temperature and humidity control equipment, repair of conductive flooring, etc. This comes under the heading of "plant modernization."

Phase III - Needs in this area are being performed under what is known as manufacturing methods and technology (MMT) projects and involved requests such as a new method of mixing pyrotechnics to decrease and possibly eliminate operator presence, a safer way of loading/unloading mixers, better protection for operators working with pyrotechnic compositions, fast response deluge systems that will work, and similar type requests. These technologies, after they are developed, will then be implemented through future plant modernization projects.

The Current Pyrotechnic Safety Enhancement Program

All aspects of the current program are outlined in appendix B. One program generated involves improving operator safety by use of a new pyrotechnic protective suit. When used in conjunction with other aspects of the overall pyrotechnic program, operator safety will be greatly enhanced with a real possibility of eliminating the current incidence of injuries and fatalities as they now occur.

Personnel Protection for Pyrotechnic Processing

For many years, the common method of protecting operator personnel processing pyrotechnic compositions was to outfit them in aluminized fire-fighting proximity clothing. This clothing varied depending on where it was purchased and by whom.

In Sep 81, a program was started to adapt from commercially available materials a new complete protective outfit, including headgear, breathing apparatus, and gloves. This program is formally titled, "Personnel Protection for Pyrotechnic Processing," and is under the management of MPBMA. Before this program commenced, an evaluation of which private/Government organization was capable of performing such work was undertaken. More than one capable organization surfaced. Based on availability of personnel and previous experience in design of protective garments, the project was assigned to the Navy Clothing and Textile Research Facility (NCTRF) located in Natick, MA. ARRADCOM, Dover (Picatinny Arsenal) was assigned to do technical coordination and provide necessary testing facilities along with all electronic data collection, photographing and subsequent analysis, and pyrotechnic composition manufacture for such tests.

Personnel from NCTRF toured the involved pyrotechnic manufacturing facilities and observed numerous operations. In addition, they also observed operations at the ARRADCOM, Dover site R&D pyrotechnic facility.

The program was divided into four sections as follows:

1. Specify a protective outer garment.
2. Specify protective headgear.
3. Specify gloves.
4. Specify emergency breathing apparatus.

Test Parameters and Material Choice

Test parameters (in items 1, 2, 3, and 4) consisted of a simulated open mixer with 15 pounds of dry granular illuminant composition placed in the "mixer." The illuminant composition used was:

Magnesium (30/50 mesh)	58 percent
Sodium Nitrate	38 percent
Binder	4 percent

From information available, approximately 40 material combinations were fabricated. After the first few tests were conducted, the majority of fabricated materials were eliminated from consideration. A sampling of the materials initially considered and tasted, along with pictures of the test setup, are attached along with a sampling of initial hood and face plate tests (appendix C).

Suit Fabrication

Based on test results, two material combinations were fabricated into completed suits. These suits were then fitted over instrumented mannequins. The completed suits differred only in the choice of outer shell material, one used a 70/30 OPF/PBI* blend while the other was 100 percent OPF.

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*OPF or PAN - oxidized polyacrylonitrite (80 percent semicarbon material)
PBI - polybenzimidazole

Final suit choice was based on physical examination after testing and analysis of temperature data, as recorded by skin simulant thermocouples placed at seven locations on the mannequins.

A sampling of the suit testing and data collection is attached in appendix D for the full suit and headgear.

The final material combination is as follows:

Outer Shell - 70 percent OPF/30 percent PBI; 15.5 to 16.5 ounces per square yard.

Insulation - Batting, PARA-ARAMID (KEVLAR), 9.3 to 11.3 ounces per square yard.

Inner Liner - Cotton cloth, Gortex laminate, 6 to 7 ounce per square yard.

The hood is a modified standard fire fighters hood design per specification with exception that, instead of the specified material, 70 percent OPF/30 percent PBI will be used and the neck and shoulder lengths extended. Tie-down straps were also added. The faceplate was modified by the addition of two 15-mil sheets of Lexan onto the outside of the standard faceplate.

The effort involved in specifying protective gloves paralleled that of the protective suit. Numerous material combinations were fabricated and tested. The final glove design consists of the following:

Outer shell - 70 percent OPF/30 percent PBI.

Middle Liner (Vapor Barrier) - neoprene-coated nylon taffeta.

Inside Liner Material - 100 percent PBI felt (14 ounce).

Thread - 40 percent PBI/60 percent kevlar (experimental).

A four-finger glove design was chosen over the standard five based on observations of pyrotechnic operations in the manufacturing area.

Forty suits have been ordered with delivery expected in the Sep - Oct 83 time frame. A more detailed description of the materials comprising the safety suit are attached in appendix E.

The suit is designed to take an external umbilical air supply. However, because of the nature of materials used in the suit, an operator can work in comfort without hookup to such a supply. An additional option is an inner face mask connected to a self-contained 3 minute emergency air supply. The umbilical air is fed through a regulator, which in turn will automatically switch on the emergency air when the pressure in the umbilical line drops or the line is disconnected. The emergency air supply can also be turned on manually by the individual operator.

Project Completion and Suit Availability

Upon receipt of the 40 suits and before the suits are distributed, another full-scale test will then be run in a simulated mixer bay. Sixteen of the suits will then be distributed for field evaluation at various Government and private installations. Half of these will be supplied with the emergency breathing apparatus. By Dec 83, a completed technical data package (TDP)/ purchase description for the entire coverall (suit, gloves, hood, breathing apparatus) will be available.

APPENDIX A

PYROTECHNIC SAFETY QUESTIONNAIRE

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General Desired Information for Evaluation of Safety in Pyrotechnic Processing

1. All chemicals used for various compositions (including solvents).

2. All pyrotechnic compositions (named along with chemical makeup) manufactured along with quantities of each on a daily, weekly, monthly, and yearly basis. (Individual batches, quantities, where applicable, will also be specified).

3. The type of blending operation used for each composition (mix-muller, tumble type blend, etc.) and subsequent dry and granulatory requirements/operations.

4. Mode of transfer (MOT) of raw materials to blender, how blender/mixer is emptied, MOT throughout operation until final item consolidation/completion.

5. During Blending: Any scrape down (in process) operations? If so, specify how, composition, quantities involved. After blending, describe cleanup along with amount of composition residue.

6. Where flammable/explosive solvents are used: any solvent sensors in use? Type of ventilation present in area.

7. In pyro processing areas, for all areas of operation, are there temperature and humidity (T&H) controls? Are they required by item TDP(s)? Are there permanent T&H readout controls within each area? If not, specify mode of checking. For each operation an answer is required.

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8. An overall plant layout is to be provided. (Reduced size but legible.)

9. All buildings within the plant that handle pyro compositions (all phases) are to be highlighted.

10. By means of chart, delineate the individual operations and compositions handled within each building.

11. An abbreviated standing operating procedure (SOP) for each pyro operation is to be written (adopt from current plant SOP).

12. Conductive flooring in processing areas? (Re item 9.)

13. Evaluation of current sprinkler, fire detection, and deluge system within plant, by individual operating areas. Where deluge systems are present, list overall system response time, i.e., uv detector sensing to water (on composition).

14. Proposed areas where fast response deluge are required/requested (r/r).

15. Proposed areas where automation of various mixing/blending are r/r.

16. Proposed areas where new equipment (replacement) are r/r.

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17. Proposed areas where T&H controls are r/r.

18. Proposed areas where new buildings are r/r.

19. Proposed areas where vapor sensors and interlocking safety doors or warning light system is r/r.

20. On areas where other improvements are r/r.

21. Where machining or grinding of pyro composition takes place, are additional safety measures needed? Reference building and list operation (re item 11).

22. If MOD/PS&ER projects are currently under way or have been funded for future years, list these and briefly describe where they are related to problem areas within the pyro area.

23. Specific areas where it is felt MMTs are needed.

24. Have sensitivity tests been run on compositions, ref in item 2, by operating plant and compared with supplied SDS? If so, provided data.

25. Are compositions in item 2 classified differently by plant then by SDS?

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26. Specify number and position of operator when items 4 and 5 are in process.

27. Any compositions that are so sensitive that future efforts at processing these will still have a high degree of risk to operator(s)?

APPENDIX B

PYROTECHNIC SAFETY ENHANCEMENT PROJECTS

Pyrotechnic Safety Enhancement Projects

Manufacturing Methods and Technology Projects

YEAR	TITLE	SYNOPSIS
1981	Personnel Protection for Pyrotechnic Processing (0977)	To fabricate a complete pyrotechnic protective suit that will offer protection to the operator against flash fires from loose pyrotechnic compositions.
1981	Preignition Detection/ Vapor Sensor (4555)	To provide an adequate means of predicting a flash fire by monitoring pyro mixes by thermography. To provide an adequate vapor sensing unit suitable for use in pyro processing areas to preclude combustible/flammable vapor buildup.
1982/ 83/84	Pyrotechnic Safety Enhancement (4548)	Contains four areas: 1. Mix muller modification to reduce waste and eliminate operator presence for manual scrapedown. 2. Provide a safe means of transporting, loading, and unloading pyrotechnic compositions within a manufacturing facility. 3. Provide positive data as to the adequacy of fast response high volume deluge systems on various pyrotechnic compositions. 4. Provide data to eliminate propagation of flash fires. Generate a mixer bay design based on specific pyrotechnic compositions.
1982/83	Improved Processing of Pyrotechnics (1709)	Develop new feeding, mixing, drying, and granulating techniques for specified pyrotechnic mixtures.

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Facility Projects

YEAR	TITLE	SYNOPSIS
1983	Pyrotechnic Temperature and Humidity Control (2250)	Provides for installation/repair of temperature and humidity control systems in manufacturing (CAAA, LCAAP, LSAAP, and PBA).
1983	Pyrotechnic Safety Enhancement - Interim Corrections (2260)	Provide for new drying ovens, conductive flooring repair, installation of remote batch feeders, replacement of worn/damaged mixers, remote unloading equipment for mix mullers, barricade replacement/installation, remote loading equipment for granulators and screeners (CAAA, LSAAP, PBA).
1985	Preignition Detector/Vapor Sensor (2240)	Provides for the facilitization of the technology developed under MMT 4555 (CAAA, LCAAP, LHAAP, LSAAP, PBA).
1986	Pyrotechnic Safety Enhancement (2245)	Provides for the facilitization of the technology developed under MMT 4548 (CAAA, LCAAP, LHAAP, LSAAP, PBA).
1986	Pyro-Remote Ignition Material Facility (2305)	Provides for the facilitization of the technology developed under MMT 1709 (CAAA, LCAAP, LHAAP, LSAAP, PBA).

APPENDIX C

FABRIC TESTING AND CONSIDERATION

Initial Fabric Consideration - Rationale

All appropriate commercially available flame resistant materials were considered along with those materials that will become available within a few years. Preliminary information indicates that along with the basic requirements of high temperature and flame resistance, the material would have to be abrasion resistant, have high tensile and tear strength and high moisture regain, and be lightweight, flexible, and comfortable. Another important parameter that required investigation prior to making finalized fabric assemblies is the "heat-to-time" relationships and type of heat generated, i.e., convective and/or conductive and confined to enclosed areas. Because of the nature of the heat, reflective aluminum coatings laminated to the outershell fabrics are not required. Also, investigation of the fire environment showed the time of maximum heat is in milliseconds to a few seconds in length. This meant that comfortable garments could be designed with minimum insulation and material thickness. Three layers of fabric were chosen in lieu of one thick fabric (without aluminization).

Fabrics made from the fibers outlined below were considered. The fibers are inherently flame resistant. Ideally, they should not decompose when exposed to heat fluxes as high as 5,000°F for short periods of time.

Available Fabrics

The Lyndon B. Johnson Space Center, Houston, TX, has intensely investigated Beta Glass fabrics and it was concluded that glass fibers exhibited low abrasion resistance and, when used in garments that experience constant flexing, will break open in a very short period of time. To meet the requirements of the Apollo Program (which is for continuous wear clothing for a few

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weeks' wear), the individual yarns were coated with Teflon before the fabric was woven, making the fabric extremely costly for the short "use-life" it exhibited.

Kynol, a phenolic fiber, when exposed to flame carbonizes at 572°F to 1,080°F, will not shrink, and continues to retain its structure after carbonizing. Kynol's tenacity of 1.7 gpd* is considered low; a Kynol/Nomex, 70/30, blend fabric is made to improve its resistance to wear. Kynol fabrics are currently made in Japan, which could exclude its use in Government clothing.

Nomex is a high temperature resistant aramid fiber and decomposes at about 700°F. It is currently being blended with 5 percent Kevlar fiber to reduce shrinkage when exposed to high heat. It must be noted that Nomex can be made flammable if the fabric is not properly finished. The use of non-Government authorized dyed fabrics and water repellent and antistatic finishes can make Nomex flammable. Powder particles accumulated on the surface of the Nomex fabric over a period of time could be dangerous to personnel and exclude the use of Nomex from consideration.

Kevlar, like Nomex, is an aramid fiber, but starts to decompose at a temperature of 930°F. The fiber will char but will not shrink; and, because it is extremely strong, it should extend the "use-life" of garments beyond all other flame-resistant fabrics.

Polyacrylonitrile (PAN or OPF) fabrics are flame and heat resistant. PAN fabrics contain partially carbonized fiber which could be an acceptable conductor of electricity. Continued heating of the fabric above 1,200°F would

*Grams per denier - an indication of fiber strength.

change it into pure carbon; however, because of the necessity to partially pyrolize the fiber, the fabric exhibited shedding and poor abrasion resistance.

PBI (polybenzimidazole) fiber exhibits superior thermal stability and excellent resistance to ultraviolet radiation. It retains 50 percent of original strength after 30 hours at 680°F exposure in air and 55 percent strength at 1,110°F in air after 1 minute exposure. Its zero strength is 1,400°F. The fabric is flame resistant and has a high moisture regain (13 percent). Cellanese Corp. is currently building a 1.0 million pound capacity plant. Pilot plant yardage of fabric is available for experimental garments.

Durette is a modified Nomex fabric. However, its continued availability is questionable.

All the fiber/fabrics discussed were considered candidate materials for this program and were given careful consideration. Selection of the best fiber/fabric combination was based on the highest ratio factor of cost, functional utility, and availability.

On-site investigation into work environment and physical stresses assisted in determining the type of garment configuration that would offer the maximum comfort and protection to personnel.

Test Apparatus Description

The test setup was prepared as shown in Figure 1. One-half of a cleaned oil drum was mounted at an elevation to simulate the bowl of a 50-pound batch mixer. Four wooden posts were placed to simulate test operators working on the "mixer," with two surface thermocouples mounted on the face of each post at approximate chest-high level, with a centerline separation of 1 1/2 inches. One thermocouple was a "skin simulant," a polyethylene resin disc (1 1/2" dia x 3/8" thick) designed to have a heat response similar to human skin; it contains a 3 mil diameter copper-constantan thermocouple placed .05cm below the surface, and is manufactured by Albany International Research. The second one, a foil thermocouple, is a fast response-(10-20 msec) copper-constantan couple made of .0005-inch foil laminated between sheets of polymer for a total thickness of .005 inch, "cement-on Style I," manufactured by Omega Engineering, Inc. It was mounted on a 1 1/2 inch diameter, 1/8 inch thick disc of cowhide using a thermally conductive silicone paste. Both types were recessed so that their thermocouple faces were flush with the wood surface. A nominal 4-foot long sleeve of the various test materials was slipped over each post to cover its upper half. For the headgear test, the posts were cut shorter so that the thermocouples were in the center of the fire fighter's hood, when it was mounted on top of the post.

Test Procedure

A 15-pound pyrotechnic charge was placed inside the simulated mixing bowl. The mixture consisted of the following:

Magnesium (30/40)	58 percent
Sodium Nitrate	38 percent
Epoxy	4 percent

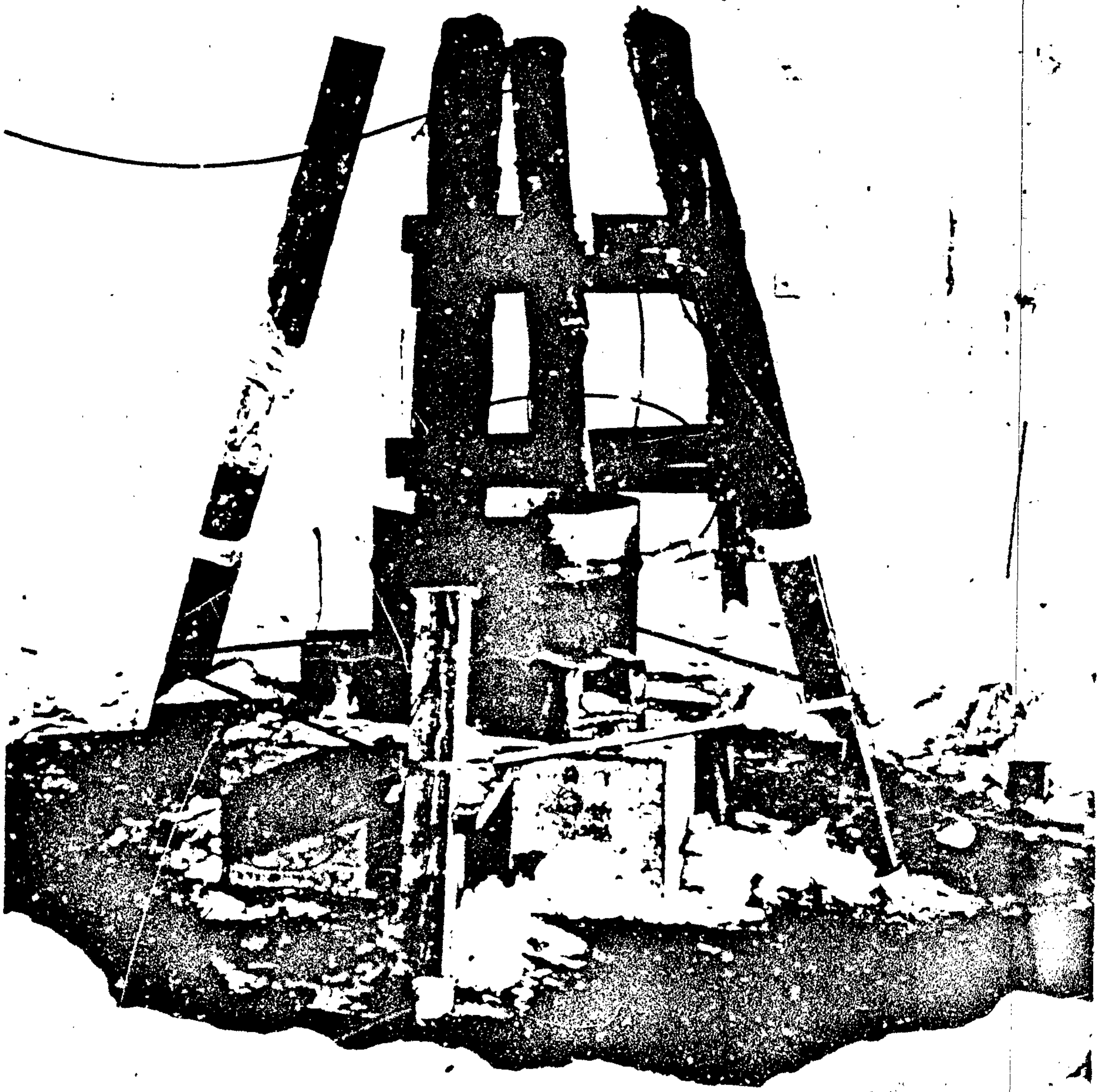
This pyrotechnic compound was ignited with an M-2 electric squib placed in a bag containing 3 grams of A-5 black powder.

A fastex and a video camera recorded all the individual tests.

Method of Evaluation

Thermal Protective Rate - "The point at which the temperature curve exceeds the threshold of pain."

A reading of "Infinity" is considered ideal.



TYPICAL TEST SETUP

FIG. 1

ACTUAL TEST

SAMPLE #16

OUTER SHELL:	20% PBI/80% Semi Carbon	15.9 oz/yd^2
INSULATION LINER:	NONE	
MOISTURE BARRIER LINING:	Gortex/Nomex	3.6 oz/yd^2
TOTAL WEIGHT (oz/yd^2):		19.5
TOTAL THICKNESS (INCHES):		.076
THERMAL PROTECTIVE RATE:		0.8
VISUAL OBSERVATIONS:	Outer shell badly charred and lining destroyed.	

SAMPLE #22

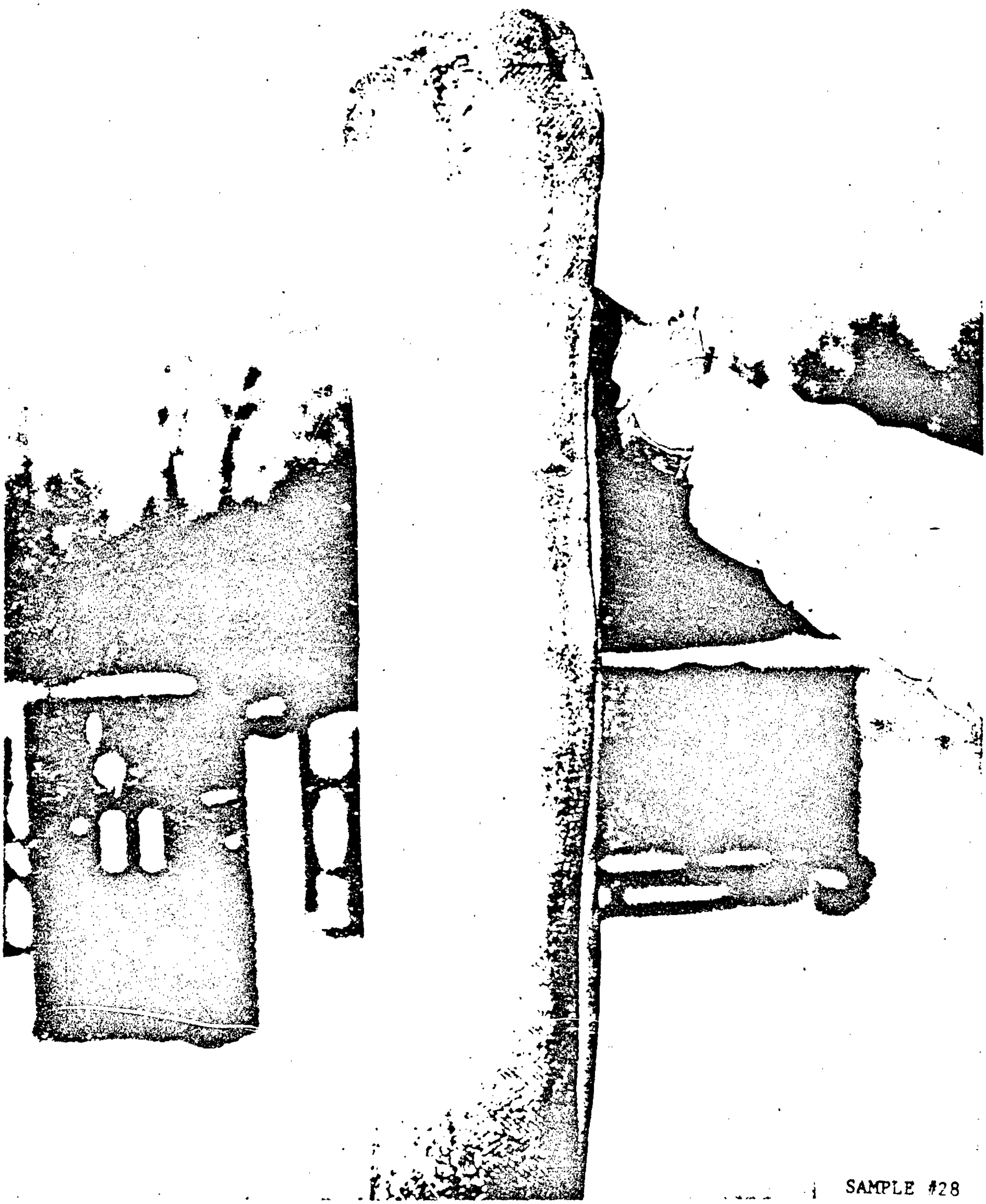
OUTER SHELL:	100% PBI	9.1 oz/yd^2
INSULATION LINER:	100% Kynol Batting	6.5 oz/yd^2
MOISTURE BARRIER LINING:	Gortex/Nomex	3.6 oz/yd^2
TOTAL WEIGHT (oz/yd^2):		19.2
TOTAL THICKNESS (INCHES):		.224
THERMAL PROTECTIVE RATE:		7.0
VISUAL OBSERVATIONS:	Material assembly destroyed.	

SAMPLE #23

OUTER SHELL:	99% wool/1% steel fiber	7.0 oz/yd^2
INSULATION LINER:	100% Kynol batting	6.5 oz/yd^2
MOISTURE BARRIER LINING:	Gortex/Nomex	3.6 oz/yd^2
TOTAL WEIGHT (oz/yd^2):		17.1
TOTAL THICKNESS (INCHES):		.219
THERMAL PROTECTIVE RATE:		No reading
VISUAL OBSERVATIONS:	The outer shell completely destroyed, charring of insulation on face surface with one burn through area, while backing of insulation showed no charring. Lining showed one burn through area.	

SAMPLE #24

OUTER SHELL:	20% PBI/80% Semi Carbon	15.9 oz/yd^2
INSULATION LINER:	100% Kynol Batting	6.5 oz/yd^2
MOISTURE BARRIER LINING:	Gortex/Nomex	3.6 oz/yd^2
TOTAL WEIGHT (oz/yd^2):		26
TOTAL THICKNESS (INCHES):		.256
THERMAL PROTECTIVE RATE:		Infinity
VISUAL OBSERVATIONS:	Charring and minor holes on outer shell fabric, slight charring on surface of insulation, and lining was unaffected.	



SAMPLE #28

SAMPLE #25

OUTER SHELL:	100% PBI	8.1 oz/yd^2
INSULATION LINER:	65% PFR Rayon/35% Wool Batting	3.8 oz/yd^2
MOISTURE BARRIER LINING:	Gortex/Nomex	3.6 oz/yd^2
TOTAL WEIGHT (oz/yd^2):		15.5
TOTAL THICKNESS (INCHES):		.232
THERMAL PROTECTIVE RATE:		0.5
VISUAL OBSERVATIONS:	Destroyed complete assembly.	

SAMPLE #28

OUTER SHELL:	20% PBI/80% Semi Carbon	15.9 oz/yd^2
INSULATION LINER:	100% Nomex Batting	6.9 oz/yd^2
MOISTURE BARRIER LINING:	Gortex/Nomex	3.6 oz/yd^2
TOTAL WEIGHT (oz/yd^2):		26.4
TOTAL THICKNESS (INCHES):		.356
THERMAL PROTECTIVE RATE:		No reading
VISUAL OBSERVATIONS:	Charring and minor burn through on outer shell fabric, insulation has a burn through of about a 6 in^2 area, and there was discoloration of lining.	

SAMPLE #29

OUTER SHELL:	100% PBI	9.1 oz/yd^2
INSULATION LINER:	100% Nomex Batting	6.9 oz/yd^2
MOISTURE BARRIER LINING:	Gortex/Nomex	3.6 oz/yd^2
TOTAL WEIGHT (oz/yd^2):		19.6
TOTAL THICKNESS (INCHES):		.324
THERMAL PROTECTIVE RATE:		0.6
VISUAL OBSERVATIONS:	Material assembly destroyed.	

SAMPLE #30

OUTER SHELL:	80% PFR Rayon/20% Nomex	7.0 oz/yd^2
INSULATION LINER:	100% Nomex Batting	6.9 oz/yd^2
MOISTURE BARRIER LINING:	Gortex/Nomex	3.6 oz/yd^2
TOTAL WEIGHT (oz/yd^2):		17.5
TOTAL THICKNESS (INCHES):		.310
THERMAL PROTECTIVE RATE:		No rea
VISUAL OBSERVATIONS:	Material assembly destroyed.	

3'

SAMPLE #31

OUTER SHELL:	100% PBI	9.1 oz/yd^2
INSULATION LINER:	100% Kevlar Batting	8.4 oz/yd^2
MOISTURE BARRIER LINING:	Gortex/Nomex	3.6 oz/yd^2
TOTAL WEIGHT (oz/yd^2):		21.1
TOTAL THICKNESS (INCHES):		.406
THERMAL PROTECTIVE RATE:		8.0
VISUAL OBSERVATIONS:	Outer shell destroyed, insulation had 1.5 ft char with one burn through, the lining material was tender and showed shrinkage.	

SAMPLE #33

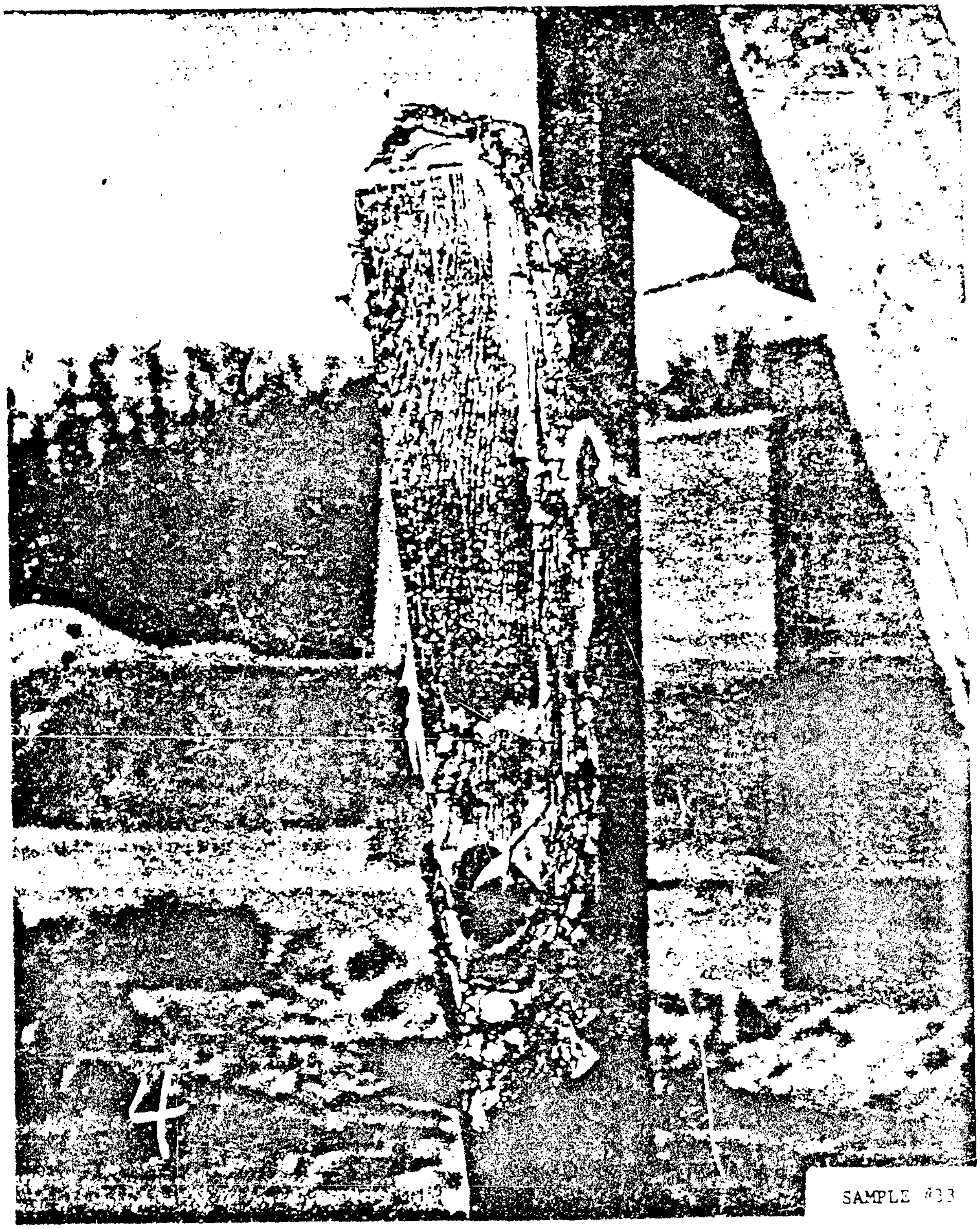
OUTER SHELL:	80% PFR Rayon/20% Nomex	7.0 oz/yd^2
INSULATION LINER:	100% Nomex Batting	4.0 oz/yd^2
MOISTURE BARRIER LINING:	Gortex/Nomex	3.6 oz/yd^2
TOTAL WEIGHT (oz/yd^2):		14.6
TOTAL THICKNESS (INCHES):		.217
THERMAL PROTECTIVE RATE:		No reading
VISUAL OBSERVATIONS:	Material assembly destroyed.	

SAMPLE #34

OUTER SHELL:	20% PBI/80% Semi Carbon	15.9 oz/yd^2
INSULATION LINER:	100% Nomex Batting	4.0 oz/yd^2
MOISTURE BARRIER LINING:	Gortex/Nomex	3.6 oz/yd^2
TOTAL WEIGHT (oz/yd^2):		23.5
TOTAL THICKNESS (INCHES):		.263
THERMAL PROTECTIVE RATE:		4.5
VISUAL OBSERVATIONS:	Outer shell had deep char, insulation, and lining destroyed.	

SAMPLE #35

OUTER SHELL:	20% PBI/80% Semi Carbon	15.9 oz/yd^2
INSULATION LINER:	65% PFR Rayon/35% Wool Batting	3.8 oz/yd^2
MOISTURE BARRIER LINING:	Gortex/Nomex	3.6 oz/yd^2
TOTAL WEIGHT (oz/yd^2):		23.3
TOTAL THICKNESS (INCHES):		.253
THERMAL PROTECTIVE RATE:		3.8
VISUAL OBSERVATIONS:	Charring and minor burn through of outer shell, installation destroyed, and minor discoloration of lining.	



SAMPLE #33

SAMPLE #36

OUTER SHELL:	100% Semi Carbon	15.0 oz/yd^2
INSULATION LINER:	100% Kevlar Batting	8.4 oz/yd^2
MOISTURE BARRIER LINING:	Gortex/Nomex	3.6 oz/yd^2
TOTAL WEIGHT (oz/yd^2):		27.0
TOTAL THICKNESS (INCHES):		.429
THERMAL PROTECTIVE RATE:		15
VISUAL OBSERVATIONS:	Outer shell material surface charred but stayed intact, surface charring of insulation, and slight discoloration of lining.	

SAMPLE #37

OUTER SHELL:	100% Semi Carbon	15.0 oz/yd^2
INSULATION LINER:	65% PFR Rayon/35% Wool Batting	3.8 oz/yd^2
MOISTURE BARRIER LINING:	Gortex/Nomex	3.6 oz/yd^2
TOTAL WEIGHT (oz/yd^2):		22.3
TOTAL THICKNESS (INCHES):		.244
THERMAL PROTECTIVE RATE:		1.5
VISUAL OBSERVATIONS:	Charring of outer shell, insulation and lining destroyed.	

SAMPLE #38

OUTER SHELL:	Grey Leather 2.5/64	
INSULATION LINER:	100% Kevlar Batting	8.4 oz/yd^2
MOISTURE BARRIER LINING:	Gortex/Nomex	3.6 oz/yd^2
THERMAL PROTECTIVE RATE:		22
VISUAL OBSERVATIONS:	The leather was destroyed and continued to show afterglow until physically extinguished, the insulation and lining showed moderate charring completely through.	

HOOD #1

Description: Hood, Firemen's, Aluminized, Proximity, MIL-H-29144A, with the exception that the metallized facepiece was removed and a clear flexible plastic film of 0.020 inches was added in the place of the metallized facepiece.

Thermal Protective Rate: 4

Visual Observation: The flexible plastic film melted away leaving facepiece support untouched, and visibility though facepiece support was good.

HOOD #2

Description: Hood, Firemen's, Aluminized, Proximity, MIL-H-29144A, with the exception that the metallized facepiece was reversed, leaving the metallized side facing in.

Thermal Protective Rate: 4

Visual Observation: The metallized facepiece melted onto the facepiece support, reducing the visibility to a minimum.

HOOD #3

Description: Hood, Firemen's, Aluminized, Proximity, MIL-H-29144A, with gold foil facing.

Thermal Protective Rate: 4

Visual Observation: The metallized facepiece melted onto the facepiece support, reducing the visibility to a minimum.

HOOD #3

3'

APPENDIX D

COMPLETED SUIT TESTING

FINAL SUIT DESIGN RATIONALE

A one piece garment was designed since it had a minimal number of openings through which flame and convective heat could penetrate and burn the wearer. Prototype samples will be produced and submitted to in-house physiological testing under the standard work environment for stress analysis. Sample prototype garments will be compared to current heat protective suits. During the same period of time, a number of experimental prototype suits will also be field evaluated.

DYNAMIC TESTING - PROTECTIVE CLOTHING

1. In order to effectively test the protective coveralls, dual mannequins were used. These were set up side by side and supported at the rear by wooden cross braces. The mannequins were inclined or angled over a mock-up blender containing illuminant composition. They were angled in such a way as to simulate operators in the act of scrape down or charging of the blender. In some test sequences, we arranged one arm so that it was directly inside the blender with the hand adjacent to the composition.

2. The mannequins were instrumented with skin simulants and thermocouples that terminated at a computer, through wire attachments. Each mannequin was instrumented to read temperatures at the following locations:

a. Right Breast
b. Left Breast
c. Pelvic Area
d. Forehead
e. Right Forearm

The computer printout recorded the ambient temperature prior to light off of the composition in the blender, then recorded the temperature rise inside the coveralls at each of the locations noted above.

3. In a typical test sequence the maximum temperature rise inside the protective coveralls was 4°F to 5°F. The exception to this was where we purposely put the hand and forearm directly inside the blender, and on these occasions we recorded a 25°F rise. Typically, the "threshold of pain" is determined at a

point from 111°F to 114°F. Considering a 25°F rise from the ambient temperature of 65°F to 70°F, it can be seen that the forearm temperature was substantially below the "threshold of pain." However, from examination of the glove that was on the hand directly adjacent to the illuminant composition in the blender, it was concluded that the temperature rise had to be substantially above that measured at the forearm. It is doubtful that any protective glove can be more efficient under those circumstances. Note that the temperature at the center of the fireball is between 4,000°F and 5,000°F.

4. In one instance, a temperature rise of 57°F on one mannequin and 25°F on the other at the forehead location were recorded. It was determined that, in assembling the protectve headdress, it was forced down (due to improper fit), causing the face piece to tilt and the frame to touch the simulant. Essentially, the air space between face plate and forehead was too small. A subsequent test wherein this was corrected resulted in the maximum 4°F to 5°F rise. The pattern for the protective headdress was modified to preclude any problem of type encountered. The attached computer printout represents the test sequence wherein the high temperature rise at the forehead was encountered.

MANNEQUIN INSTRUMENTATION

The mannequins were instrumented as follows for data as collected:

Mannequin No. 1		Mannequin No. 2	
Line	Location	Line	Location
1	Right Breast	2	Right Breast
3	Left Breast	4	Left Breast
5	Pelvic Area	6	Pelvic Area
7	Forehead	8	Forehead
9	Right Forearm	10	Right Forearm

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MATERIAL/THERMAL RESISTANCE TEST

(COMPUTER LINES 1-10) TEST #3

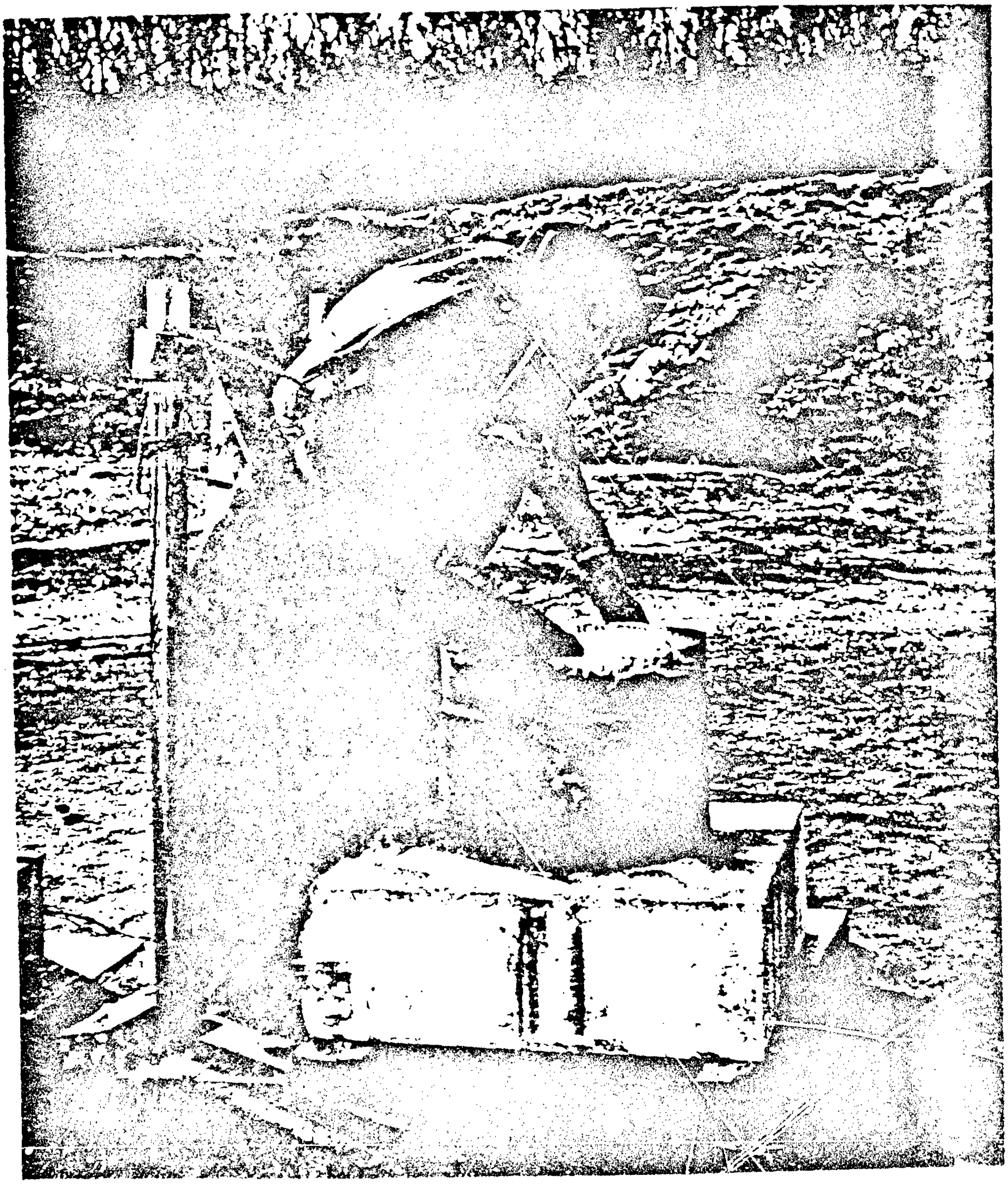
TIME = 0 SEC TEMP - DEG. F.

1	2	3	4	5	6	7	8	9	0
53	51	53	51	52	47	65	65	51	36

DIF. TEMP. - DEG. F.

	1	2	3	4	5	6	7	8	9	0
TIME = 1 SEC	0	0	0	0	0	0	0	0	0	0
TIME = 2 SEC		0	0	0	0	-1	0	-1	-1	-1
TIME = 3 SEC		1	2	1	1	-1	0	-1	-1	-1
TIME = 4 SEC		0	0	0	0	-1	0	-1	-1	-1
TIME = 5 SEC		0	0	0	0	0	0	-1	-1	-1
TIME = 6 SEC		0	0	0	0	-1	0	-1	-1	-1
TIME = 7 SEC	0	0	0	0	0	-1	3	4	-1	-1
TIME = 8 SEC	0	0	0	0	0	0	16	29	0	-1
TIME = 9 SEC	0	0	0	0	0	0	24	49	0	0
TIME = 10 SEC	0	1	1	1	1	0	25	55	0	0
TIME = 11 SEC	0	0	0	0	0	0	25	57	2	0
TIME = 12 SEC	0	0	0	0	0	0	22	55	4	0
TIME = 13 SEC	0	0	0	0	0	0	20	51	5	0
TIME = 14 SEC	1	0	1	0	0	0	19	49	8	-1
TIME = 15 SEC	2	1	1	1	1	0	17	45	8	0
TIME = 16 SEC	2	1	1	1	0	0	16	42	10	0
TIME = 17 SEC	1	0	0	0	0	0	15	39	11	0
TIME = 18 SEC	1	0	0	0	0	0	15	37	11	0
TIME = 19 SEC	2	1	2	1	0	0	14	35	12	0

COMPOSITION PLACED IN MIXER WITH MANNEQUINS IN POSITION
(FIGURE AT LEFT IS TEST OPERATOR)



MANNEQUINS BEFORE BLAST OF 15 LBS OF DRY GRANULAR ILLUMINANT COMPOSITION

LOST OFF OUTER SHELL

AFTER IGNITION

70 30 OPF/PBI OUTER SHELL

Inside 70/30 Suit After Test

HOOD - 70/30 OPF/PBI OUTER SHELL

APPENDIX E

DETAILED MATERIAL AND PURCHASE DESCRIPTION

5\

Requirements

Cloth, Flame, and Heat Resistant

Quantity/Width - Linear yds - 40-inch width, min

Estimated Cost - $30.00/yd

Inspection/Acceptance - At destination

<u>Reporting Test Results.</u>

The contractor shall be responsible for supplying a test report for the fabric specified in this contract. The contractor may use his own or any other facilities suitable for the performance of the testing requirements as specified unless disapproved by the Government. The Government reserves the right to perform any of the tests set forth in the requirements where such tests are deemed necessary to assure the fabric conforms to the specified requirements.

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Specification

Cloth, Flame, and Heat Resistant

Polybenzimidozole-Oxidized-Polyacrylonitrile

1. Guide Sample. Samples when furnished are solely for guidance and information to the contractor. Variation from this specification may appear in the sample, in which case this specification shall govern.

2. Requirements.

a. Fibers. The fibers used for the wrapping portion of the finished yarn shall be polybenzimidozole (PBI) natural in color (tan). The core of the finished yarn shall be oxidized-polyacrylonitrile (OPF). The resulting color shall be natural (black).

b. Yarn. The OPF core yarn shall be a ten singles worsted count, made from high density (1.4 gms/c^3), high tenacity (1.7 gms per denier) partially oxidized OPF. The yarns for both warp and filling shall be of a 1/10 worsted count OPF yarn made by wrapping a PBI yarn around the core yarn with the resulting yarn two plyed. The fiber content of the final two plyed OPF/PBI yarn shall be 70 percent OPF and 30 percent PBI made to equal the standard sample.

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TABLE I

Fabric Requirements

Characteristics	Requirements MIN	Requirements MAX
Weight, oz/yd^2	15.5	16.5
Yarns per inch		
Warp	31	-
Filling	21	-
Weave	2/2 Herringbone Twill repeating on 15 ends	
Breaking Strength - LBS		
Warp	190	-
Filling	130	-
Tear Strength LBS		
Warp	35	-
Filling	33	-
Air Permeability FT^3/minute/FT^2	25	35
Shrinkage percentage		
Warp	-	5.5
Filling	-	3.0
Thickness/inches	0.040	-
Flammability Resistance		
After Flame (seconds)		1
After Glow (seconds)		1
Char Length (inches)		1
Fiber content, percent PBI	30	-
OPF	-	70
Width, inches	40	-

TABLE II

Test Methods

Federal Test Method Standard 191

Characteristic	Requirement	Test Method
Weight	Table I	5041
Yarns per inch	"	5050
Weave	"	Visual
Breaking Strength (Warp & Filling)	"	5100
Tear Strength (Warp & Filling)	"	5132
Air Permeability	"	5450
Shrinkage	"	5556 1/
Thickness	"	5030 2/
Flammability Resistance	"	5903
Fiber Content	"	3/

1/ Cotton mobile Laundering

2/ Para 4.1.1 of TM 5030, 0.6 PSI ± 0.03 PSI
Diameter of pressure foot - 1.129 inches

3/ The contractor shall furnish a certificate of compliance for this characteristic.

Requirements (KEVLAR)

Batting, Para-Aramid (KEVLAR)

Quantity/Width - Linear yds - 60-inch width, min

Estimated Cost - $9.15/Linear yd

Inspection/Acceptance - At destination

Reporting Test Results.

The contractor shall be responsible for supplying a test report for the fabric specified in this contract. The contractor may use his own or any other facilities suitable for the performance of the testing requirements as specified unless disapproved by the Government. The Government reserves the right to perform any of the tests set forth in the requirements where such tests are deemed necessary to assure the fabric conforms to the specified requirements.

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Specification

Batting, Para-Aramid

1.0 Guide Sample. Samples when furnished are solely for the guidance and information to the contractor. Variation from the specification may appear in the sample in which case this specification shall govern.

2.0 Materials.

2.1 Aramid fiber staple. The cut staple fibers used in the batting shall be a high strength, medium modulus aramid with a minimum fiber tenacity of 20 grams per denier. The filament shall have a linear density of 1.5 denier per filament. The fibers shall have a nominal length of 2 inches. The color (yellow) shall be that as produced by the manufacturer. Bleach or color modifiers shall not be used.

2.2 Scrim. The scrim used in the construction of the finished batting shall be made of polyester and weigh a minimum of 1.8 ounces per square yard; when tested as specified in Table II.

2.3 Batting (unsupported). The unsupported batting shall be made of the material specified in 2.1. The batting shall be needled with approximately 240 penetrations per inch (PPI) of width. The batting shall weigh approximately 2.56 ± 0.26 ounces per sqare yard, when tested as specified in Table II.

2.4 Batting, finished. The finished batting shall be constructed of one layer of scrim (2.2) positioned between one layer of batting (2.3) on one side and two layers of batting on the other side. The scrim and layers of batting shall be needled together with approximately 210 penetrations per inch of width. The finished batting shall conform to the requirement of Table I when tested as specified in Table II.

2.4.1 Eveness of batting. The eveness of the finished batting shall be to the degree that no single determination shall deviate more than 0.6 ounces per square yard from the mean of 5 specimen when tested as specified in Table II.

Table I - Requirements for Finished Batting

Characteristic	Requirements MIN	 MAX
Weight, oz/yd^2	9.3	11.3
Thickness	0.34	0.42
Compression Recovery, percent	80.0	-

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TABLE II

Test Methods

Batting Para-Aramid-Kevlar

Characteristics	Requirements	Test Methods
Finished Needled Batt		
Weight, oz/yd^2	Table I	*5041 1/
Thickness, inches (0.01 PSI)	"	Para 4.5.1 1/
Compressional Recovery, %	"	Para 4.5.2 1/
Eveness of Batting, oz/yd^2		*5041 2/

*Federal Test Method Standard 191

1/ Test specimens shall be allowed to relax on a flat surface without pressure for a minimum of 24 hours, until equilibrium with standard conditions is reached, prior to subjection to tests.

2/ For the eveness test, the weight shall be determined by using an 8 x 8 inch specimen.

4.5.1 Determination of thickness. Thickness of the batting filler shall be determined in accordance with the method specified in 4.5.2 for "Initial thickness of specimen."

4.5.2 Determination of compressional recovery.

4.5.2.1 Preparation of specimen. The specimen shall be cut from different parts of a full width sample and shall measure not less than 6 inches by 6 inches. The specimen shall always be larger than the pressure foot on the test apparatus.

4.5.2.2 Apparatus. The test apparatus shall consist of a base plate and a circular pressure plate with a bearing surface of 20 square inches, and a means of applying 0.01 and 5.0 pounds per square inch loading on the sample. This pressure shall be evenly distributed over the 20 sqare inch area. The thickness measuring device shall be capable of measuring the thickness of the sample (distance between base and pressure plate) to an accuracy of 0.01 inch.

4.5.2.3 Procedure. The 0.01 pound per square inch pressure shall be applied to the test specimen, and the thickness reading shall be taken and recorded as "initial thickness" (see 4.5.1). Immediately after determining the initial thickness, the pressure shall be increased to 5 pounds per square inch and maintained for one minute. The pressure shall then be completely removed and the specimen shall be allowed to relax for 5 minutes. Immediately after the 5 minute relaxation period, the thickness of the specimen shall again be determined under 0.01 pound per square inch pressure and be recorded as the "thickness of the specimen after compression."

4.5.2.4 Calculation of results. The percent compressional recovery shall be determined by the following formula:

$$\text{Percent compressional recovery} = \frac{\text{Thickness of specimen after compression}}{\text{Initial thickness of specimen}} \times 100$$

The percent compressional recovery shall be determined from five specimens and the results averaged and recorded to the nearest 1 percent.

Requirements

Coverall, Protective

Quantity - 40 each

Estimated Cost - $510 each

Inspection/Acceptance - At destination

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Requirements

Cloth, Cotton, Laminated, Fire Resistant

Quantity/Width	- Linear yds - 45 inch width, min
Estimated Cost	- $12.35/yd
Inspection/Acceptance	- At destination

Reporting Test Results.

The contractor shall be responsible for supplying a test report for the fabric specified in this contract. The contractor may use his own or any other facilities suitable for the performance of the testing requirements as specified unless disapproved by the Government. The Government reserves the right to perform any of the tests set forth in the requirements where such tests are deemed necessary to assure the fabric conforms to the specified requirements.

Specification

Cloth, Cotton, Laminated, Fire Resistant

1. Guide Sample. Samples when furnished are solely for guidance and information to the contractor. Variation from this specification may appear in the sample, in which case this specification shall govern.

2. Materials.

a. Base Fabric. The cloth shall be 100 percent cotton, modified basket weave with two ends and two picks weaving as one. The color shall be natural. The fire retardant finish shall be one of the treatments on the approved list prepared by the US Army Natick Research and Development Command. The cloth shall conform to the physical requirements listed under Table I when tested as specified under Table II.

b. Plastic Film. The plastic film shall be polytetrafluorethylene microporous, 0.5 ± 0.1 ounces per square yard. The color shall be natural or white.

c. Laminated Cloth. The base fabric specified above shall be laminated to the plastic film specified above. The face of the laminated cloth shall be the fabric side. The laminated cloth shall conform to all the requirements of Table II when tested as specified under Table III.

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TABLE I

Physical Requirements

Base Fabric

Characteristics	Requirements MIN	MAX
Weight, oz/yd^2	5.5	6.5
Yarns per inch		
Warp	94	-
Filling	72	-
Breaking Strength, LBS		
Warp	75	-
Filling	45	-
Tear Strength, LBS		
Warp	5	-
Filling	5	-
Yarn Ply		
Warp & Filling	Singles	
Flammability Resistance		
Warp & Filling		
After Flame (seconds)	0	
After Glow (seconds)	5	
Char Length (inches)	6	

TABLE II

Physical Requirements

Laminated Cloth

Characteristics	Requirements	
	MIN	MAX
Weight, oz/yd^2	6.0	7.0
Breaking Strength, LBS		
Warp	82	-
Filling	64	-
Tear Strength, LBS		
Warp	4	-
Filling	4	-
Hydrostatic Resistance, PSI		
Initial	100	
After strength of coating	100	
After high humidity	100	
Stiffness, CM		
Warp		12
Filling		8.5
Hydrostatic Resistance to Leakage	No leakage	
Moisture Vapor, gm/M^2/24 hrs		
Transmission Rate	550	
Flame Resistance, Warp & Filling		
After Flame (seconds)	2	
After Glow (seconds)	8	
Char Length (inches)	5	

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TABLE III

Test Methods

Federal Test Method Standard 191

Characteristics	Requirements	Test Methods
Weight	Tables I & II	5041
Breaking Strength	" "	
Warp & Filling	" "	5102
Tear Strength	" "	
Warp & Filling	" "	5132
Yarns per Inch	" "	5050
Hydrostatic Resistance		
Initial	Table II	5512 1/
After Strength of Coating	"	5972 2/ & 5512 1/
After High Humidity	"	Para 4.1
Stiffness	"	5204
Resistance to Leakage	"	Para 4.2
Moisture Vapor Transmission Rate	"	7032B 3/
Flame Resistance		
Warp & Filling	Tables I & II	5903

1/ The water pressure shall be applied to the coated side of the laminated cloth.

2/ Except that the specimens shall be stretched at 20 pounds.

3/ Method of testing specified in FED-STD-406, 50 or 61. The coated side of the laminated cloth shall face the water.

4.1 After high humidity. Three 4 by 4 inch specimens shall be laid flat, face side up, on a supporting plate and the assembly placed in a desiccator containing water in the lower portion. The water level shall be approximately 1 inch below the specimens. The lid of the desiccator shall be put in place and the desiccator placed in a circulating air oven having a temperature of 160° ± 2°F for a period of seven days. At the end of the aging period, each specimen shall be removed from the desiccator and tested immediately in accordance with Method 5512 of FED-STD-191 with the water pressure being applied to the face side.

4.2 Resistance to leakage. The test for resistance to leakage shall be conducted as specified in Method 5516 of FED-STD-191, except that the face side of the laminated cloth shall contact the water. The hydrostatic head shall be 50 centimeters, and shall be held for ten minutes. The report shall only include measurement of the appearance of water drops.

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SCOPE OF WORK

Specification

Coverall, Protective

1. Requirement. Manufacture pyrotechnic protective clothing in the following sizes and in accordance with the specification data below:

Item	Quantity	Size
Coverall	15	Large
Coverall	25	Medium
Hood	40	-

2. Specification: The coveralls are composed of three layers; an outershell fabric (30 percent polybenzimidozole (PBI) and 70 percent oxidized-polyacrylonitrile (OPF)), an 8.0 ounce Kevlar needle punch batting material used as the insulating medium and a Gortex coated cotton liner.

The coverall is a front opening double zipper design; where each zipper extends from the neck down the center of each leg. There shall be hidden Nomex wristlets in each sleeve and an elastic, hidden leg closure sleeve in each leg.

The modified MIL-H-29144 hood shall be manufactured according to the specification with the following exception: The hood shall be manufactured from the identical materials as the coverall. The hood shall contain a neck sleeve with elastic button and underarm straps.

3. Government Furnished Material (GFM):

a. The Government shall furnish the necessary patterns and guide samples to the contractor.
b. OPF/PBI Material
c. Kevlar Batting
d. Gortex Coated Cotton
e. Zippers
f. Automatic Brass Locking Slider
g. Universal Top Stop
h. Staple, Bottom Stop

4. Preproduction Sample: Prior to production of the total quantity, the contractor shall furnish a preproduction sample of the coverall and one hood for approval. Cutting of the material for the entire order shall be witheld until approval is final. Preproduction and approval shall be accomplished within 10 days of receipt of the GFM. Approval of the preproduction sample shall be in written form and the approved sample will constitute part of the total quantity of 40.

5. Guide Sample: Samples when furnished are solely for guidance and information to the contractor. Variation from this specification may appear in the sample, in which case this specification shall govern.

6. Inspection/Acceptance: Final inspection and acceptance shall be at the contractor's plant. Such inspection shall be conducted by personnel of the Navy Clothing and Textile Research Facility. Notification of conformity or nonconformity shall be in writing to the cognizant PCO at ARDC who will notify the contractor of acceptance or rejection of the items.

7. Sewing Thread: The following will be used exclusively in sewing the garments:

Thread, Para-Aramid, Spun

Intermediate Modulus

Specification: MIL-T-44100

Size: T50

Color: Black

RETROSPECTIVE

Prepared By: JOHN BLACK

For the 25th ANNIVERSARY CELEBRATION of the
EXPLOSIVES AND PYROTECHNICS APPLICATIONS
SECTION of ADPA

RETROSPECTIVE

I would like to present some historical information concerning Fuze Programs that I was priveleged to work on from 1940 through 1975 and also highlight two great military leaders who made major contributions to Fuze Development and Production: General Levin Campbell and Admiral George Hussey. All historical facts are documented in two text books: "The Industry - Ordnance Team", by General Campbell and "The Deadly Fuze", by Ralph Baldwin. The latter contains an introductory section and letters by Admiral Hussey. I have both books here if anyone would care to brouse through them, both contain interesting WW II photographs.

General Campbell served as a director of the American Ordnance Association in 1951, was elected President of the AOA in 1953 and became Director for Life in 1960. Admiral Hussey succeeded General Campbell as President of the Association. General Campbell served as Commanding Officer of the Artillery Ammunition Division of Frankford Arsenal from 1939 until he became Chief of Army Ordnance in 1942. During his tour of duty at Frankford, one of his primary fields of interest was engineering and production of Mark 18 and M-43 Mechanical Time Fuzes. The fuze shop of the Artillery Division became a fuze research center and also a training facility for Industrial Fuze contractors, fuze production was expanded.
After becoming Chief of Ordnance, General Campbell became deeply involved in Mechanical Time Fuze production planning and organized a Mechanical Time Fuze Integration Committee to assist prime fuze contractors in procurement, training, and scheduling, to meet the increasing requirements for anti-aircraft weapons early in 1942. This was the first of a number of industry integration committees for ordnance production. There were seven fuze contractors operating during peak production years, the largest one produced both Mark 18 and M-43 fuzes, one contractor also developed and manufactured dynamic regulation equipment, a 2-channel system servicing both Mark 18 and M-43.

Admiral Hussey spent several years as a gunnery officer in the 1930's and had considerable experience with powder train delay fuzes on Navy anti-aircraft projectiles. He had grave concern for wide time spread in the early pyrotechnic fuzing, and the minimal number of bursts close on target. This condition stimulated his interest in mechanical time fuzes under development and engineering in Frankford Arsenal. He became Chief of the Ammunition Section, Bureau of Ordnance in 1936 and pioneered procurement of Mark 16 time fuzes for the Navy. This activity was interrupted by additional sea duty lasting through 1941. In 1942 the Admiral returned to the Bureau of Ordnance and eventually was appointed Chief of the Bureau. He immediately became involved in procurement and production of radio proximity fuzes under development and in preliminary production, remained actively engaged through WW II and into post-war development programs. Admiral Hussey was the highest ranking Naval officer actively involved in radio proximity fuze procurement and production. Proximity fuzes were designed for both anti-aircraft and field artillery applications, gave excellent performance against enemy aircraft, V-1 flying bombs and enemy ground forces in WW II. Mechanical Time and Radio Proximity Fuze Programs were radically different during WW II, the design concept of the mechanical fuze was frozen when it was released for production, no re-design was permitted, only process engineering for cost reduction and increased production of parts occurred within fuze contractor's operations.

Early design concepts for a radio proximity fuze existed in 1940. Applied Physics Laboratory / Johns Hopkins University became the agency responsible for development and design of the fuze. By May 1941, a design appeared adequate, models were made and a successful test was accomplished aboard a Navy 5 inch / 38 shell in June 1941. A production contract was implemented in January 1942, followed by additional contracts through the war years, with design changes and improved models, the design was never frozen. January 1943 saw the first deployment of Navy 5 inch shells carrying proximity fuzes, in the Pacific. Proximity Fuzes were coded VT, a deceptive term suggesting variable time, supporting very rigid security that was needed not only to prevent duplication of fuzes by our enemies, but also to ensure that no radio frequency counter-measures would be developed. The design concept of the VT Fuze was never discovered by either enemy.

Following the end of WW II, the Navy assigned responsibility for post-war development of VT Fuzes to Naval Ordnance Laboratory, presently Naval Systems Weapons Center. This program has been continuous since November 1945, many improved models have been developed and also produced in a contractor's facility. Transition from radio tubes to solid state was accomplished in this continuing effort. The contractor designed improved safety and arming devices, performed extensive testing to verify explosive safety and performance, along with safety engineering to support safe storage, handling, and testing. Explosive systems in mechanical time fuzes and radio proximity fuzes were radically different, in both design criteria and handling safety.

M-43 and Mark 15 time fuzes contained a percussion primer initiated by a firing pin. A powder bag was detonated by the primer. No handling safety problems existed during fuze assembly and test since primers and powder bags were installed in isolated loading areas. There was no out-of-line safety, therefore, final fuze handling safety was dependent upon mechanical interlocks in the fuze mechanism. A set-back pin locked the firing pin, spin sensitive interlocks locked the gear-train. As for firing safety, stripped gears after set-back could cause a muzzle burst, locked gears would cause a dud. Stripped gears in flight would result in a premature. Recovered duds were unsafe for disposal.

Original VT fuzes contained no out-of-line safety, only electrical safety of the Mark 114 electric primer was provided by a shorting wire which was broken on firing. Muzzle bursts could occur with premature firing of the primer. The first improvement was a spin sensitive mercury switch that maintained a very low resistance short across the primer for 1/2 second of projectile spin. The next improvement was a separate safety and arming device containing a clock timer, the electric primer and electrical safety, and an out-of-line safety feature consisting of a metal gate between the primer and relay charges. Advantages were reliable out-of-line safety for handling and delayed arming activated by spin. Disadvantages were large dimensions, restricting its use to larger shells having deeper wells. Later on, an auxiliary detonator assembly with spin sensitive gates containing relay detonators was used in conjunction with fuzes having only electrical safety.

This device provided additional handling safety, however, muzzle bursts could occur with premature primer firing.

Post-war developments provided an improved safety and arming device having reliable out-of-line safety. It contained a clock mechanism driven by spin forces, a rotor with a relay detonator, an electric primer with electrical safety. This device was essential to overall safety because the Mark 114 wire bridge had been replaced by the Mark 124 sensitive carbon bridge primer. Changing electric detonators drastically reduced the size of firing capacitors, therefore, improving the electronic package configuration. The disadvantage was a more hazardous electric primer. This device was produced in several models to accomodate various shell spins from 40 to 450 RPS. It also contained a spin sensitive destruct switch that was activated by drop in spin. This was essential for destroying shells that would land as duds in the event of electronic failure in the fuze.

After WW II, development of a photo-flash bomb system was undertaken for improvement of night time aerial photography, using M-1 500-pound flash bombs produced by Picatinny Arsenal. Objectives were simultaneous detonation of bombs after sequential high altitude drops, reliable low temperature operation of fuzes, and overall ground and aircraft safety. There were two components in the fuzing system - A wind driven safety and arming device was mounted in the bomb nose well. This device contained a spring activated rotor with relay detonator, a 0.1 ampere wire bridge primer with electrical safety and a bomb release wire locking the wind driven 10 second delay mechanism. A standard bomb booster cup was attached to the base of the S & A and was detonated by the primer, relay detonator and a lead charger. By reason of convenience and generous space allowed, this arming device was over designed for safety and gave very reliable performance. Exhaustive safety and functional tests verified safety and reliability in a temperature range from +40 to -85 degrees F. A ground test was organized in Aberdeen Proving Ground for an overall fuze and bomb function. A fuzed bomb was placed on the ground, with 1000 feet of arming wire and firing line running to a block-house containing firing equipment and other instrumentation. For unknown reasons this test was a failure. ("We pushed the button and nothing happened.")

Although determination of cause of failure would have been valuable, Aberdeen Proving Ground made a good decision to detonate this dangerous flash bomb with a Comp. C shaped charge rather than remove the fuze at high risk. The second component consisted of an electric and mechanical fusing system attached to the bomb using internal threads in the tail well, and fired the electronic primer through internal wiring inside the bomb. Several successful low altitude drop tests were completed. Testing verified handling and transport safety, however, the fuze did not have ground impact destruct features and therefore, was not safe for disposal. This was an experimental program, made obsolete by newly developed infra-red photographic systems before high altitude tests were accomplished.

The Military Pyrotechnics Committee was organized during this flash bomb fuzing system development program. In 1957, early in the Hawk Missile Program, it was considered feasible to design a safety and arming device for the warhead that would be technically farther advanced and could supercede the existing arming device currently in production. The objective was the development of accelerometers responding to forward acceleration, then arming the rotors, replacing mechanical timing devices driven by G weights. A new S & A was developed containing a different accelerometer concept plus interesting functional and safety interlock features. The arming and explosive system was redundant - two electric detonators, two rotors with relay detonators, two separate lead-in charges running into the RDX warhead. Protruding safety pins prevented the S & A from fitting into the warhead if the device was armed and also served as safe-arm indicators. Electric primers were fired simultaneously by the electronic package of the missile. A command destruct system consisted of a small relay inside the S & A, operated on ground command and fired the detonators from charged capacitors also inside the S & A. An impact switch inside the S & A fired the detonators on target impact, also on ground impact if there was no command destruct. Exhaustive testing verified explosive safety when detonators were fired in full out-of-line safety, again in partial out-of-line. Telemetered tests with the S & A on board engineering flight tests of the Hawk verified all functions of the S & A. Several live warhead tests at White Sands Missile Range resulted in unusually close bursts on drone targets. Although very successful flights were accomplished, zero failures, the program was abandoned because of questionable features of the accelerometers which were somewhat experimental, even though the S & A was otherwise basically sound

Only one mishap occurred during this S & A testing program. Presumably a crack in the solid rocket propellant caused a heavy detonation instead of a steady burn, when the igniter was activated. Although there was massive destruction of the missile, the warhead fell on the ground with the S & A in a fail-safe condition, as it was designed. The ordnance engineer handed me the S & A and said, "Here is a present for you." I was required to report the event to the S & A contractor who was on his way to a status meeting for the contract at Picatinny Arsenal, the sponsoring agency. The contractor's project liaison officer said, "Holy cow, I hope it wasn't our fault."

RESUME JULY 1983

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Work in Ordnance Activity began in 1940 at Gibbs Research Corporation, the inventors and producers of dynamic regulation equipment for the Mechanical Time Fuze (MTF). Two (2) years were spent in development testing, field service and installation of spin test equipment in the several associate fuze contractors' facilities.

2. Two (2) years (1942 and 1943) were spent in Franksford Arsenal on service, maintenance, and design modifications of spin test equipment for the MTF, and on liaison engineering with other MTF contractors.

The following thirteen (13) years were spent in Eastman Kodak Company, one of the contractors producing both the Mechanical Time Fuze and the Radio Proximity Fuze. At the end of World War II, Kodak became the prime development contractor and producer of Proximity Fuzes. Engineering work in the post-war development program included design of high speed dynamic test equipment for Safety and Arming Devices (S and A), also the testing of reserve energizers, explosive components, and final proximity fuze assemblies.

Approximately three (3) years were spent in the design and prototype production of the T 763 Photo Flash Bomb Fuze by Kodak. Engineering work included the selection and testing of explosive components, field testing, and safety engineering.

The following two (2) years were spent in field testing and safety engineering of a Safety and Arming Device also produced by Kodak for the original Hawk Missile.

6. The remaining years to retirement from Kodak in 1973 included design and field testing of weapons systems and proprietary programs that were not directly fuze related.

7. The three (3) years following retirement were spent in design, reliability, and safety engineering for the XM 734 Mortar Fuze produced by Kodak, while employed by Flint & Sherburne Associates, a consulting engineering firm and also a defense contractor.

CONTROLLED FRAGMENTATION OF TAPERED CYLINDERS

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ABSTRACT

Methods for controlling the fragmentation of cylinders have been fairly well established. Several methods have been developed, the most effective of which take advantage of the metals' ability to shear along trajectories determined by the stress distribution and geometric relationships of the cylinder expansion resulting from detonation. One of the more recent methods involves the application of a heavy-metal wire grid to the exterior surface of the cylinder.

The application of the wire grid system to a tapered cylinder, or frustum, presents a special case which is not as easily solved. It is shown that the surface of a frustum may produce controlled-shape fragments, using a wire grid an overlay pattern generated with computer graphics.

INTRODUCTION

Missile warheads generally consist of a metal cylinder filled with an explosive composition. On detonation, the cylinder (or case) ruptures, producing fragments of high velocity which cause damage and inflict casualties in the vicinity of the detonation. If no method of controlling the fragmentation is employed and the case is allowed to fragment naturally, a distribution of large and small fragments will be produced, varying in shape as well as size. It is apparent that these fragments will vary in kinetic energy as well, and for this reason considerable attention has been given to the production of uniformly-shaped and sized fragments through controlled fragmentation processes, so that area and energy distributions can be optimized.

Methods for controlling the fragmentation of cylinders have been fairly well established. Several methods have been developed, the most effective of which take advantage of the materials' natural tendency to shear along the trajectories determined by the stress distribution and geometric relationships of the cylinder expansion resulting from detonation. One of the more recent methods involves the application of a heavy-metal wire grid as an overlay around the external surface of the cylinder (Ref. 1). In this system, a grid of lead (Pb) wires, oriented to produce diamond-shaped fragments, was applied to the surface of a cylinder to form included angles of 60 degrees, which has been found to yield an optimized control pattern.

ANALYSIS

The problem of controlling the fragmentation of a tapered cylinder is not as easily solved. The geometry of a (hollow) conical frustum is shown in Figure 1. In the figure, D_L is the major diameter of the frustum, D_S is the minor diameter, and L is the altitude or vertical height of the frustum. If the surface of the frustum is developed, then it is apparent that the arc AB is the minor circumference of the frustum and the arc CD is the major, while r_S is the lesser radius required to generate the surface, and $r_L + r_S$ is the larger, where r_L is equal to the slant height of the frustum. If the arc AB is to be divided into an integral number of segments of a given length, and the same number of segments is to be produced across the arc CD, then it is apparent that these intervals cannot be equal in arc length to those across the arc AB. The only way that the surface ABCD can be divided into equally sized fragments is to project equi-spaced straight lines, as spokes, proceeding from the origin of the included angle θ. This would produce tapering segments of length r_L, but not many fragments would be generated.

If a grid were to be laid out to utilize the natural tendency of the material to fragment along trajectories of arcs intersecting at 60 degrees, those diamond-shaped fragments originating along the arc AB will be smaller than those generated as rupturing of the metal sleeve occurs toward the arc CD, and the ability to produce equally-sized fragments is sacrificed. However, to compensate for this variation, the wall thickness of the sleeve may be tapered so that the larger fragments will be thinner, and the individual fragments will tend to be equal in weight.

The solution to the problem of producing arcs intersecting at 60 degrees and dividing arcs AB and CD into an equal and integral number of segments is shown in Figure 2. In the figure, a line drawn from the origin through one of the straight legs of the frustum envelope is taken as the X-axis, and a line through the origin perpendicular to it taken as the Y-axis. Using the nomenclature from Figure 1,

$\theta = \frac{\pi D_S}{s}$ = the included angle of the envelope

β = arc intersect angle, set to 60 degrees,

n = number of divisions selected, an integer, usually even

$\alpha = \frac{\theta}{n}$, central angle division,

$S_H = \sqrt{L^2 + \left(\frac{D_L - D_S}{2}\right)^2}$ = slant height of frustum = r_L

$r_S = \frac{D_S S_H}{D_L - D_S}$ = shorter radius of envelope,

and t = defined incremental change in angle α termed a generator.

The curves shown in Figure 2 may be generated by using these parameters in conjunction with the following equations for the coordinates.

$$X = r_S \cos(\alpha + t)\exp(t \tan \beta)$$

and $$Y = r_S \sin(\alpha + t)\exp(t \tan \beta)$$

where $0<\alpha<\theta$

and $$0<t<\frac{\ln\left(\frac{r_L + r_S}{s}\right)}{\tan \beta}$$

For example, at the point B in Figure 2, $t = 0$ and $\alpha = 0$. The expressions given are for the (X,Y) coordinates of points generated in one direction, say from right to left. For trajectories in the opposite direction, the sine and cosine expressions require a sign change, i.e., $\cos(\alpha + t)$ becomes $\cos(\alpha - t)$, and $\sin(\alpha + t)$ becomes $\sin(\alpha - t)$. An interactive FORTRAN program written to produce the graphics on a Gould plotter is given in Appendix A of this report.

CONTROLLED FRAGMENTATION TESTS

For testing of the lead-wire-grid controlled fragmentation method, a typical shaped charge munition, shown in Figure 3, was loaded with cast 70/30 Octol explosive. A wire grid made up of 0.030-inch (0.75-mm) lead wire was overlaid on a paper pattern generated by a computer program described in Appendix A of this report. The grid with paper was taped over the exterior conical surface of the case.

The arena configuration used for this test is illustrated in Figures 4 and 5, which portray side and end views of the collecting tank and test stand. Stainless steel stripper plates were employed so that ricocheting fragments or other debris could be separated magnetically from the steel fragments generated by the case itself. The height was selected to maximize the distance between the charge and the stripper plates; this distance resulted in a stripped "window" opening of 32.4 degrees of arc.

Fragments from the test firing were collected in the water tank positioned below the charge, dried and screened. Because of the limited aperture for collecting, the number of fragments recovered was also limited, but those collected are shown in Figure 6, superimposed on a paper grid pattern to show the conformity of fragment shapes with those predicted by the control method. The agreement with the pattern and the effectiveness of the control method were deemed so successful that further testing was not required to demonstrate the utility of the method.

Applications of this method, U.S. Patent No. 3799045, are subject to the provisions of the U.S. Patent Office.

Reference

1. E. W. LaRocca, "Controlled Fragmentation of Large Cylinders", presented at the 1980 meeting, ADPA, 28 October, 1980, Crane, Ind.

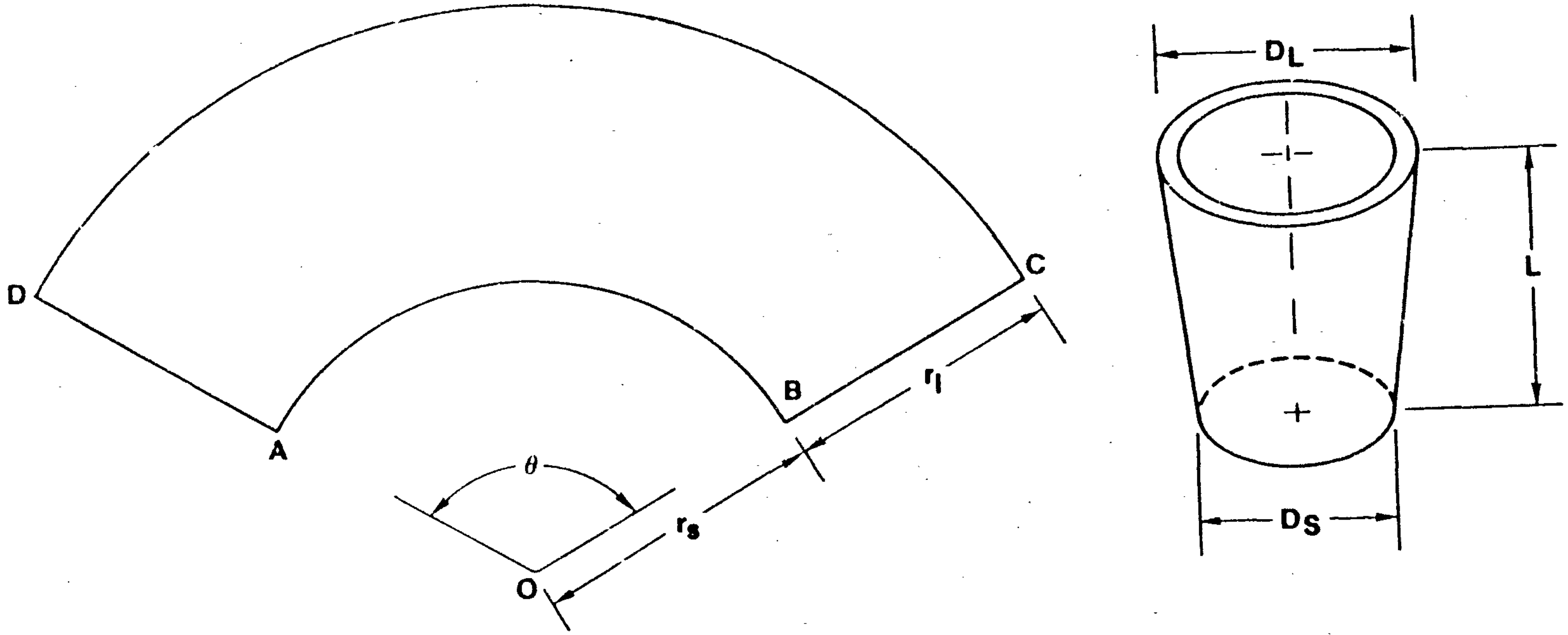

FIGURE 1. GEOMETRY OF THE HOLLOW CONICAL FRUSTUM

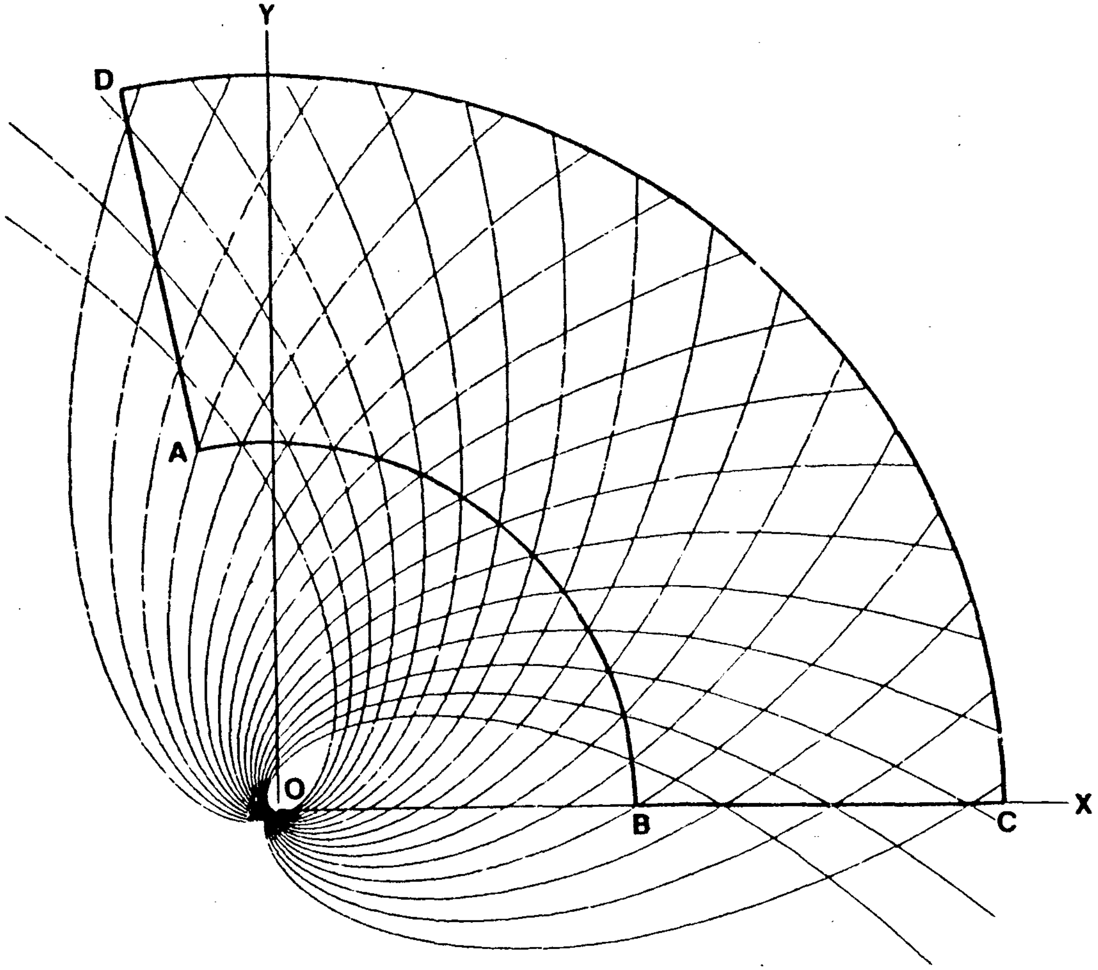

FIGURE 2. COMPUTER SOLUTION OF ARCS INTERSECTING AT 60 DEGREES, SUPERIMPOSED ON THE SURFACE OF A FRUSTUM

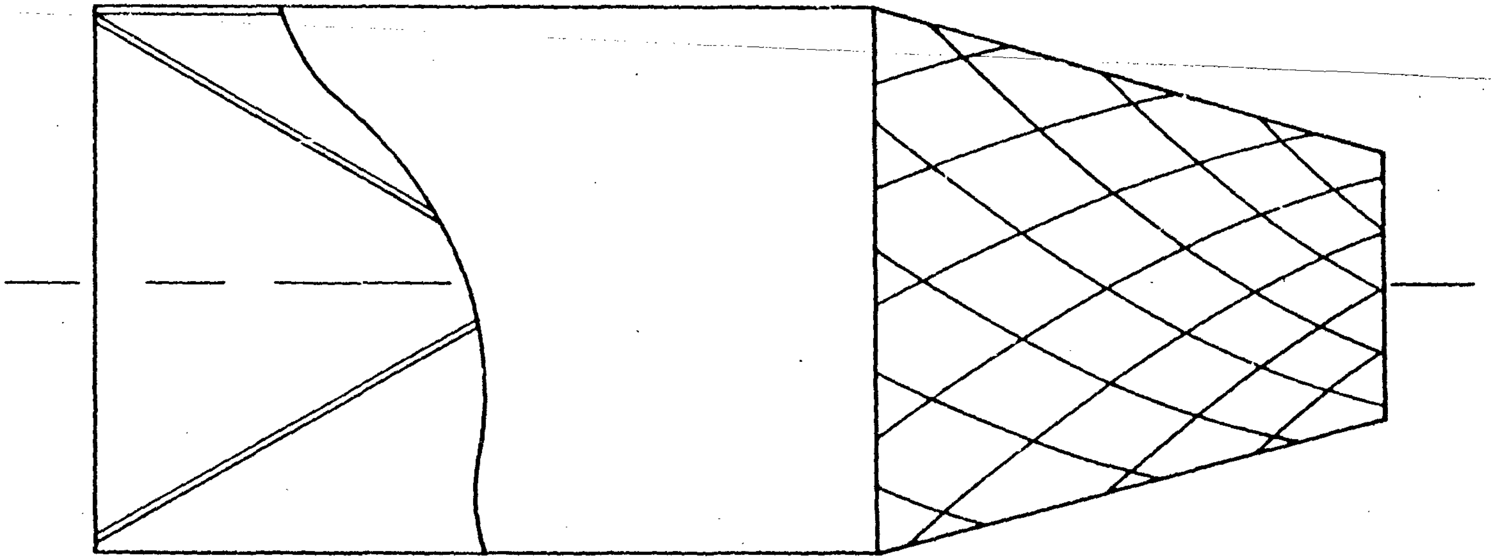

FIGURE 3. TYPICAL SHAPED CHARGE MUNITION WITH FRAGMENTING AFT END

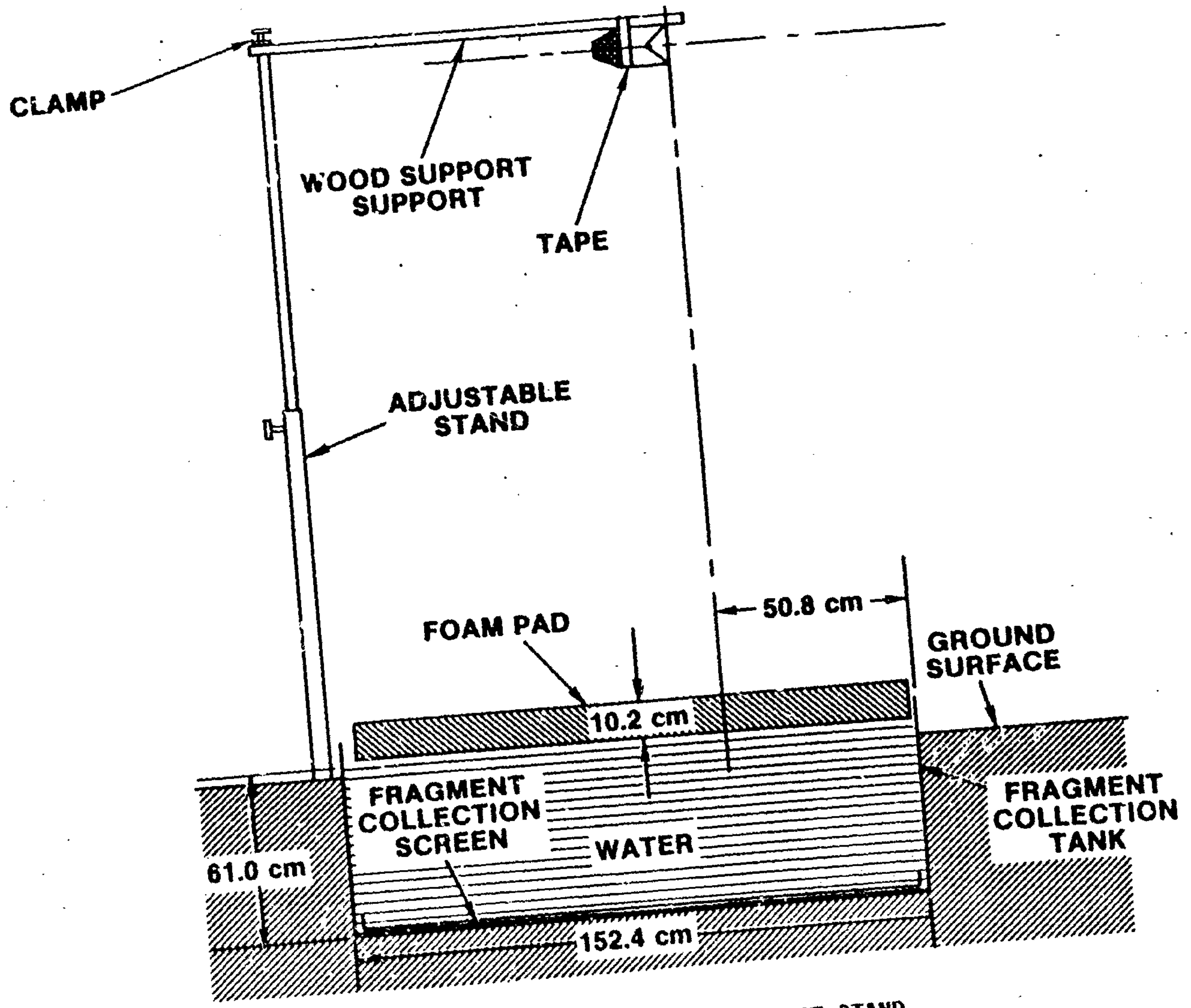

FIGURE 4. SIDE VIEW OF TEST STAND

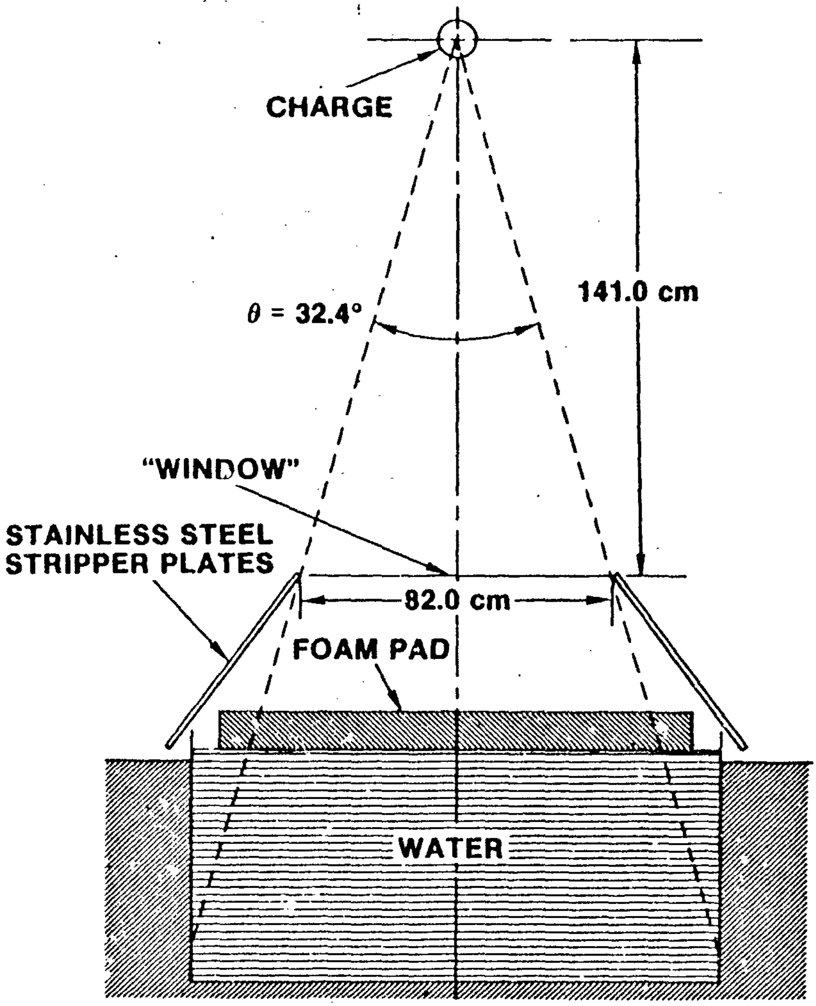

FIGURE 5. FRONTAL VIEW OF TEST STAND

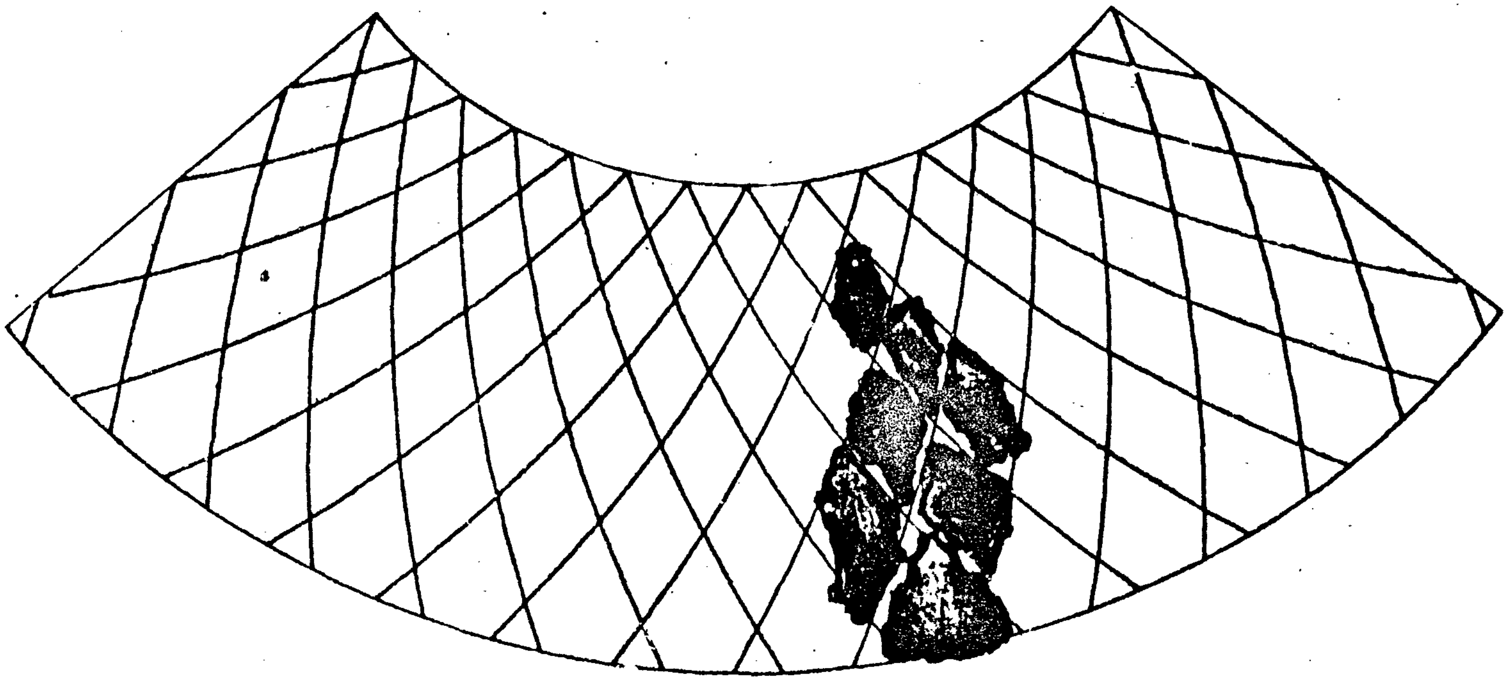

FIGURE 6. TYPICAL RECOVERED FRAGMENTS SHOWING SHAPE CONTROL

APPENDIX A

Program FRAG is a Fortran program which computes trajectories of points forming specified angles of intersection across the envelope of a truncated cone, or frustum. Output is in graphic form, and presents a grid of intersecting exponential curves, all meeting at a specified angle. Sources of each curve lie on the circumference of the minor diameter of the frustum. Separation, or spacing between sources, is at the option of the designer. In the example given, the spacing is input at 14, or the minor circumference of the frustum is divided into 14 equal arcs. The angle of intersection is also arbitrary, but in this case has been set to 60 degrees, since experience has shown this to be an effective generator of controlled-size/shape fragments.

For the example shown in Figures 2 and 3, the required input is:

DS = minor diameter of frustum in inches = 1.5750

DL = major diameter of frustum, in inches = 3.1880

L = altitude of frustum (perpendicular height) in inches = 2.7430

NC = number of segments dividing the circle = 14 (always an integer)

ND = number of points defining each line = 50 (machine prints 4 times this number for resolution)

BETA = included angle of intersection (degrees)

The graphics program will produce a chart of trajectories of all points, superimposed on an envelope describing the surface of the frustum.

```
      PROGRAM FRAG(INPUT=65,OUTPUT=65,PLOT=65,TAPE19=PLOT)
C
      DIMENSION X(501), Y(501), XX(2,2), YY(2,2)
      REAL LS
      DATA XMIN / 1.0 /, XMAX / 10.0 /, YMIN / 2.5 /, YMAX / 10.5 /
      DATA XXMIN / -2.0 /, XXMAX / 7.0 /, YYMIN / -1.5 /, YYMAX / 6.5 /
      DATA PI / 3.14159265 /
C
      READ 2, DS, DL, XL
    2 FORMAT( 3E10.0 )
C
      LS = SQRT(XL ** 2 + ((DL - DS) / 2.0) ** 2)
      RS = DS * LS / (DL - DS)
      RL = RS + LS
      THE = PI * DS / RS
      PRINT 4, DS, DL, XL, LS, RS, RL, THE
    4 FORMAT( 1H1, /,
     A          4H DS , E14.5, //,
     B          4H DL , E14.5, //,
     C          4H L  , E14.5, ////,
     D          4H LS , E14.5, //,
     E          4H RS , E14.5, //,
     F          4H RL , E14.5, //,
     G          4H THE, E14.5, )
C
      READ 6, NC, ND, BETA
    6 FORMAT( 2I5, E10.0 )
      PRINT 5, NC, ND, BETA
    5 FORMAT( ///, 4H NC , I14, //,
     A             4H ND , I14, //,
     B             5H BETA, F13.5, )
      BETA = BETA * PI / 180.0
C
      DTHE = THE / NC
      BETAC = TAN(BETA)
      TMAX = ALOG(RL / RS) / BETAC
      DT = TMAX / ND
      NC1 = NC + 1
      ND1 = 9 * ND + 1
C
      CALL OBJEG(XMIN, YMIN, XMAX, YMAX)
      CALL PAGE
      CALL SUBJEG(XXMIN, YYMIN, XXMAX, YYMAX)
C
      TBEG = 2.0 * THE
      SIGN = 1.0
      TOL = 0.001
      DO 30 L = 1, 2
      SIGN = -SIGN
      TBEG = TBEG - THE
      ANG = TBEG
      PRINT 65
65    FORMAT(1H1)
      I = 0
20    I = I + 1
      IF  (I .GT. NC + 3)  GO TO 30
      ANG = ANG + SIGN * DTHE
      PRINT 7
```

```
7       FORMAT(//)
        K = 0
        JJ = 0
        T = -(8 * ND + 1) * DT
        DO 10 J = 1, ND1
        T = T + DT
        DUM = RS * EXP(T * BETAC)
        TEMP = ANG - SIGN * T
        Q = DUM * COS(TEMP)
        R = DUM * SIN(TEMP)
        DUM = ATAN2(R, Q)
        GO TO 9
        K = K + 1
        GO TO 11
9       JJ = JJ + 1
        X(JJ) = Q
        Y(JJ) = R
11       CONTINUE
     10 CONTINUE
        IF  (K .GE. ND1)  GO TO 30
        CALL LINEG(JJ, X, Y)
        GO TO 20
     30 CONTINUE
C
        DTHE = DTHE / 4.0
        NC1 = NC * 4 + 1
        ANG = THE + DTHE
        DO 50 I = 1, NC1
        ANG = ANG - DTHE
        X(I) = RS * COS(ANG)
        Y(I) = RS * SIN(ANG)
     50 CONTINUE
        CALL LINEG(NC1,X,Y)
        XX(1, 1) = X(1)
        YY(1, 1) = Y(1)
        XX(1, 2) = X(NC1)
        YY(1, 2) = Y(NC1)
C
        ANG = THE + DTHE
        DO 60 I = 1, NC1
        ANG = ANG - DTHE
        X(I) = RL * COS(ANG)
        Y(I) = RL * SIN(ANG)
     60 CONTINUE
        CALL LINEG(NC1,X,Y)
        XX(2, 1) = X(1)
        YY(2, 1) = Y(1)
        XX(2, 2) = X(NC1)
        YY(2, 2) = Y(NC1)
C
        CALL LINEG(2, XX(1, 1), YY(1, 1))
        CALL LINEG(2, XX(1, 2), YY(1, 2))
C
        CALL EXITG
        STOP
        END
```

DEVELOPMENT OF A THIRTY-FIVE SECOND DELAY CUTTER FOR THE SRB DROGUE PARACHUTE

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Space Ordnance Systems
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The key to successfully deploying the SRB Parachute System is a family of mechanically initiated pyrochemical time-delay reefing-line cutters. This family of cutters utilizes the same mechanical components but provides five different delay times. A change in the trajectory for the STS-9 and -11 Shuttle Missions will result in drogue chute deployment occuring at a lower altitude. The main chutes are deployed at a fixed altitude and a real possibility exists for the drogue to be disreefing during or slightly after main deployment. This would mean that the mains would be deployed during the highest peak loading of the drogue. To preclude this event, the second-stage Drogue Cutter delay was changed from a nominal 12 to 35 seconds. This change presented a formidable technical challenge because the configuration envelope was not relaxed. This paper presents the successful approach used to obtain the 35 second delay time as well as several methods that proved unsuccessful.

INTRODUCTION

Space Ordnance Systems supplies five different time delay reefing line cutters for use in the Space Shuttle Solid Rocket Boosters Recovery System. The five cutters have time delays of zero, seven, ten, twelve and sixteen seconds. The cutters are utilized in the drogue pack restraint straps, the drogue parachute, and the three main recovery chutes. Due to a change in the trajectory scheduled for STS -9 and -11, deployment of the drogue chute will be approximately 1,000 feet lower than on previous Space Shuttle flights. Since the main parachutes are deployed at a fixed altitude of 6,000 feet by a barometric switch, there is a real possibility for the second stage twelve-second Drogue Cutter to function during, or slightly after, main chute deployment. This would mean that the main chutes are being deployed during the highest peak loading of the drogue parachute. To preclude this potentially disastrous event, Space Ordnance Systems was requested to provide a longer (35 second) delay cutter to ensure that the drogue peak loading event would occur well after main parachute deployment. This change presented a formidable technical challenge because the configuration envelope was not relaxed in order to maintain the qualification status of the basic design and also allow usage of the same procedures and methods employed during cutter installation and chute packing.

The Drogue Chute is 54 feet in diameter, and has a design limit load of 270,000 pounds. This compares to the recovery weight of 175,000 pounds for the expended boosters. The chute has two reefing stages, one at seven seconds and another at twelve seconds, which utilizes two reefing cutters per stage placed 180 degrees apart, in a redundent application. The reefing lines cut during both stages of disreefing are rated at 36,000 pounds. The function of the drogue chute is to rotate the descending SRB into a tail first orientation so that the cluster of three main parachutes can be deployed without the risk of entanglement.

REEFING LINE CUTTER DESIGN

The existing reefing line cutter design and envelope are presented in Figure 1. The design is modular in construction with each major component capable of being removed from the assembly. The major components consist of an initiation mechanism, housing, blade anvil and delay cartridge assembly. All inert components are identical and interchangeable.

The delay cartridge assembly is presented in Figure 2. Again, all the components (both energetic and inert) of the delay cartridges (with the exception of the delay composition formulation) are identical. This includes the percussion primer, ignition composition, transfer charge output propellant and cartridge hardware components, sealants, etc. The delay composition is tungsten per MIL-T-23132. Two different burning rates of this delay composition are utilized, namely 15 and 25 - second per inch to obtain the required delay times. The zero second delay uses A-1A ignition composition per MIL-P-2226 compressed the full length of the housing to the transfer charge. The body of the delay housing is stainless steel and the pressing diameter is 0.200 inch. All compositions are consolidated at 32,000 psi.

OPTIONS TO INCREASE DELAY TIME

Due to the constaints imposed by using the existing envelope configuration, the options available for increasing the time delay were narrowed down to the following:

1. Increase the length of the delay housing along with corresponding associated parts, without violating the envelope.
2. Slow the burning rate of the delay composition to approximately 40 seconds per inch by decreasing the percentage of tungsten in the formulation.
3. Extend the burning rate of the tungsten delay composition by the addition of low melting additives such as calcium fluoride or magnesium oxide.

Option three was not considered a viable approach due to the lack of documented data for the usage of the additives to the delay compositions in qualified devices. James Rose of NOS, Indian Head has reported a dramatic increase of fifty percent in the burning rate of a basic 38-second per inch tungsten delay composition by the addition of calcium fluoride in Ref. (1). Magnesium oxide has been added to the zirconium-nickel delays with an extension to their burning rate in a similar fashion. However, criticism relative to the use of a non-specification type material could easily be voiced and this option was not considered further.

It was concluded that the approach to be employed would be a combination of options 1 and 2. Prior to any changes in the hardware, the existing design was evaluated using a 43 second per inch burning rate tungsten delay composition. The composition was consolidated to the maximum length available (identical to the sixteen second delay used on the second stage reefing line cutter of the main parachutes) and functional tests resulted in delay times of 27.5 and 29.7 seconds at ambient temperature. These results were gratifying even though the 35-second delay requirement was not obtained. It was

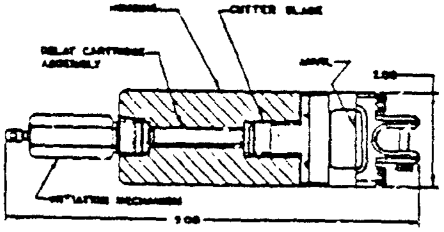

FIGURE 1: CUTTER ASSEMBLY

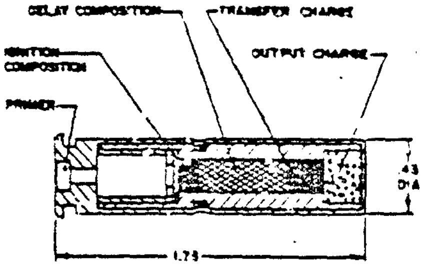

FIGURE 2: DELAY CARTRIDGE ASSEMBLY

felt that with some internal component rearrangement the required delay would be achieved. In order to accomplish this, the piston portion of the knife blade was modified to allow for the extension of the delay cartridge into it to compensate for the increased length of the delay cartridge. This is shown in Figure 3. The goal was to obtain the maximum length possible by this change. Component hardware drawings were changed and an approximate 37 percent increase in compressed delay composition was possible.

The mechanical alterations were not considered as Class I changes which would invalidate the qualification status of the cutter. The reduction of mass from the knife-piston was considered to have no effect on the sealing ability, strength or cutting capability of the cutter.

EVALUATION TESTING

Upon receipt of the redesigned component hardware, evaluation testing was conducted to determine the delay time that would be obtained using the 43 second per inch burning rate tungsten powder in the lengthened configuration. The initial test results indicated a problem; the units initiated but the delay composition was extinguished and the cutter failed to function. Sectioning of the specimens indicated that the delay composition did not react any further into the delay than twice the length of igniter material used for its ignition. Analysis of the result indicated that any or all of the following could result in the condition obtained:

- Insufficient heat was being supplied by the weight of igniter used
- An excess amount of heat was being lost from the system
- An inadequate amount of heat was being transferred into the unreacted delay

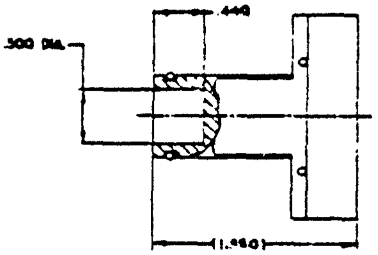

FIGURE 3: CUTTER BLADE ALTERATION

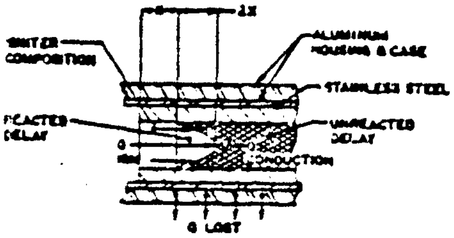

FIGURE 4: CROSS-SECTION OF EXTINGUISHED DELAY AND HEAT TRANSFER CONDITIONS.

The illustration in Figure 4 depicts the observed condition of the sectioned specimens coupled with the heat transfer associated with the system.

To correct the premature extinction of the delay composition a number of approaches were possible, each having its own merits, as outlined below.

If the igniter weight is the critical parameter, an increase in weight can readily be accomplished. However, this will result in decreasing the length which was a prime objective required for the longer delay. An alternate solution would be the use of a two-stage delay system that interjects a faster burning rate delay of the same composition between the igniter material and the slower burning rate delay. The faster burning rate material will result in additional heat generated during its reaction.

Heat losses to the surroundings can be reduced by removal of metal in the cutter housing which surrounds the delay cartridge. This essentially places an air insulator around the cartridge and changes the conductivity value from that of aluminum to air, a change from approximately 120 to 0.020 Btu/hr-sq ft - °F. However this change can be a double edged sword; air will act as an insulator but the advantage of heat conduction through the metal to the unburned delay is reduced. An additional change for the prevention of heat loss can be obtained by insulating the delay housing prior to insertion into the delay cartridge case.

The rate of heat transfer by conduction can also be a critical controlling factor. This rate is expressed by the equation $Q = kA\Delta t/\Delta x$. The major parameter that can be changed in the delay element to result in a significant change in the heat transfer rate into the delay is the cross sectional area or consolidation diameter.

Initially the approach of adding an air gap insulator around the delay cartridge was pursued primarily because a number of assembled delay cartridges were available. The diameter of the cutter housing surrounding the delay was machined larger which resulted in 0.030 air gap between the delay cartridge and cutter housing. Test units were functioned; however they did not indicate any improvement. The air gap insulator was not adequate to overcome the heat losses and again snuff out of the delay resulted. Dissecting these units indicated that very little change in the penetration of the reaction front into the unburned delay had occured. This was similar to the results which had been observed previousously.

The next attempt to overcome the extinguishing problem was to increase the heat energy into the system by coupling a two-stage delay composition system. This is shown in Figure 5. The approach employed the use of a faster burning rate (25 seconds per inch) tungsten delay compostion placed between the igniter material and the slower (43-second per inch) tungsten delay composition. The relative length ratio of each was 25/75. The faster burn-rate delay compositon is used exclusively as the delay for the sixteen-second cutter for the second-stage reefing of the SRB's main parachutes. Therefore, a fair degree of confidence was indicated that a substantial increase in heat energy to the system would result by the reaction of this material without sacrificing a great deal of available delay length. Specimens were assembled and functioned. Unfortunately, the additional heat from the faster burning delay was still not capable of overcoming the snuff-out problem. Sectioning of the specimens indicated that the reaction front had penetrated into the slower burning rate composition to a length of 60 to 70 percent prior to its self extinguishment. These results clearly indicated the need for either adding an insulation material at the location of the delay composition or to change the material and diameter of the delay housing.

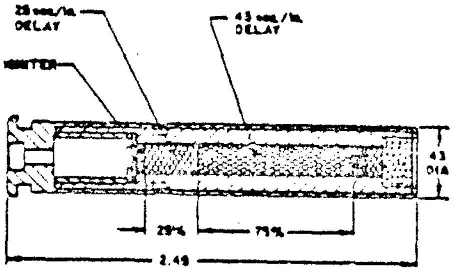

FIGURE 5: TWO STAGE DELAY SYSTEM

The latter change was not pursued because component hardware had all been procured, received and the required delivery date was imminent. Therefore, the existing exterior diameter of the delay housing was reduced by machining at the full length location where the delay composition is pressed from a diameter of .490 inch to .390 inch. A wall thickness of approximately .100 inch remained after machining. A low thermal conductivity material capable of being applied to this location was obtained. The material chosen was a two-part silicone rubber material from Dow Corning (material number 93-104) having a thermal conductivity of 5.6×10^{-6} Btu/Ft-sec-°F. The material is easily troweled for applicatio and can be fully cured in three hours at +200°F.

Test specimens were assembled using this material and also incorporating the previous modifications, i.e., the air-gap insulator of the cutter housing and the loading of a two-stage delay composition. The delay cartridge assembly is presented in Figure 5. The specimens were functionally tested at +20 °F and +120 °F. All units performed satisfactorily by severing 36,000-pound nylon webbing the cutter aperture. The delay times were all acceptable and ranged between 38 and 45 seconds. The

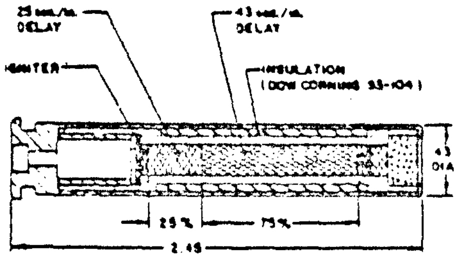

FIGURE 6: TWO STAGE DELAY SYSTEM WITH INSULATION

addition of the insulation material prevented the heat losses from the system and resulted in a sustained reaction of the slow burning rate delay. Additional specimens were assembled to verify the performance obtained from these units. This evaluation was equally successful. The function times of both groups are presented in Table I.

TABLE 1

EVALUATION AND VERIFICATION TEST RESULTS

INITIAL SPECIMENS			
Time, secs	Temp, °F	Time, secs	Temp, °F
38.20	+120	45.58	+20
40.14	"	45.52	"
39.92	"	43.20	"
		42.72	"
VERIFICATION SPECIMENS			
Time, secs	Temp. °F	Time, secs	Temp, °F
35.06	+200	46.24	+20
36.71	"	42.92	"
36.29	"	45.09	"
37.67	"		
39.58	"		
34.32	"		

DELTA QUALIFICATION

With the demonstrated success of the verification test specimens, a twelve unit delta qualification test program was conducted. Specimens were subjected to a Drop Test, Vibration, Shock, Temperature Cycle and Functionally tested. A matrix of the delta qualification tests and functional results obtained is presented in Table II. At the successful conclusion of the delta qualification test program, the 35-second delay cutter was considered qualified for use on the STS -9 and -11 vehicles SRB Drogue Chute recovery system.

CONCLUSIONS

A review of the development program conducted to achieve a longer delay in a fixed configuration envelope provides the following summarizing conclusions for solving a similar requirement:

- If a slower time delay composition will not react or snuffs-out during its reaction, the addition of an insulating material in the immediate vicinity of the delay material to inhibit heat transfer is more beneficial than any other approach.
- Proper rearrangement of pyrotechnic materials and mechanical components can be utilized to obtain a longer delay. It should not be necessary to sacrifice delay length for fast burning ignitor material.
- Material and consolidation diameter changes of delay housings are not mandatory when using a slow burning rate delay. The use of existing consolidation tooling does not have to be compromised.

TABLE II

DELTA QUALIFICATION TEST MATRIX

TEST REQUIREMENT	TEST GROUP A 6 Units	 B 6 Units
8 - Foot Drop	All	-
Shock	-	All
Vibration	All	All
Temperature Cycle	All	All
Functional Tests	2 units at each of three temperatures.	
Temperature, °F	+20	+20
Time, secs	44.94 46.20	44.37 45.08
Temperature, °F	Ambient	Ambient
Time, secs	42.13 43.48	42.87 43.75
Temperature, °F	+200	+200
Time, secs	35.97 38.72	36.57 35.83

REFERENCES

(1) J.E. Rose, "Burn Time Extension in Modified Tungsten Delay", 10th Symposium On Explosives And Pyrotechnics, February 1979

1983 Annual Meeting
PYROTECHNICS AND EXPLOSIVES APPLICATIONS SECTION
of the
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27, 28 and 29 September 1983

GENERAL DYNAMICS
Ft. Worth, Texas

TITLE Deflagration-to-Detonation Transition in Dispersing Pyrotechnic Powders

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ABSTRACT

The IIT Research Institute has previously demonstrated that typical pyrotechnic fuel-oxidizer systems can be induced to detonate under appropriate conditions, i.e., particle size of the constituents, confinement, initiation type, etc. In this paper we will describe additional in-house studies wherein explosively dispersing pyrotechnic systems, e.g., aluminum powder and ammonium perchlorate sensitized with a small amount of nitroguanidine, will initially start to deflagrate but under the right conditions will transit into detonation.

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GENERAL DYNAMICS
Ft. Worth, Texas

TITLE	Development of the XM76 Screening Grenade		
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ABSTRACT

The U.S. Army has installed smoke grenade launchers on many of their combat vehicles to provide a self-protection smoke screening capability under certain combat situations. These systems launch red phosphorus grenades in a 110 degree arc in front of the vehicle and are effective in defeating visual observation of the vehicle for a period of time. The XM76 is being developed to extend the screening capability of the system to include the entire visual through far IR spectral region.

The new grenade uses a high explosive burster to disseminate the compacted smoke composition. To provide out-of-line safety per MIL-STD-1316 a unique low-setback, no-spin S&A mechanism is included. Six components are included in the explosive train which, with the smoke composition, are housed in a sealed injection molded plastic body. This paper describes the grenade design and outlines the tests which have been conducted to develop the explosive train.

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GENERAL DYNAMICS
Ft. Worth, Texas

TITLE Current Developments of Titanate Coupling Agents in Propellants, Pyrotechnics and Explosives

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ABSTRACT

Previous papers have dealt with titanate applications in propellants, pyrotechnics and explosives. Continuous dialogue with producers and users has provided impetus for continued development of both new titanate coupling agents, a better understanding of their chemical interaction with energetic materials and new suggestions and data on their use in specific systems. For example, previously recommended commercially available pyrophosphato titanates, such as KR 38S and KR 238S, have had to be revised in their chemical makeup in order to take into account the end block termination effects caused by the alcohol content of the aforementioned coupling agents in urethane binder systems such as R4SM (Poly BD) based urethane binder systems. Two titanates, KR P38U and KR 238U, for ammonium perchlorate and aluminum, respectively, are the result. In addition a new titanate -- KR 91B having nitrobenzyl organic ligands -- has been devised for HMX particulate. Also, the authors have gained an appreciation of the chemical mechanistic interaction of the titanates between the aluminum, AP, HMX, isocyanate, R4SM polyol, and aziridine commonly used in new generation urethane propellant systems. The authors will deal with these chemical reactions and propose a technique and sequence of addition so as to maximize propellant formulation performance. Another new titanate, KR 5544, containing both allyl and primary amino functionalities will be suggested for carbon black filled Poly BD adhesives used to bind propellant to peroxide cured EPR canister liners. Also, recommendations as to the proper titanate and amount for various solid propellant insulation polymer composites will be made. Initial tests with pyrophosphato and phosphato titanates in AP/AL/R45HT catacene rocket fuel show significant changes in burn rate and burn rate exponent. For example, the pyrophosphato titanate increases the burn rate from 0.7 seconds for the control to 1.2 seconds with pyrophosphato titanate while the phosphato titanate reduces the burn rate to 0.55 seconds. The paper will, therefore, serve to update attendees on the state of the art as it relates to titanate coupling agents.

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GENERAL DYNAMICS
Ft. Worth, Texas

TITLE Short History of Pyrotechnic Advancements Made in General Dynamics Fort Worth Division Programs

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ABSTRACT

A brief description of pyrotechnic advancements used in aircraft weapon delivery and escape systems and in space vehicle separation at the Fort Worth Division. Several first-of-a-kind applications and new concepts were developed for the B-58, F-111, F-16, and Atlas Centaur programs. These items and their applications will be reviewed.