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# Flame Weapon for the SUU-24/A Dispenser

by

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Ordnance Division

Atlantic Research Corporation

TECHNICAL REPORT AFATL-TR-67-24
**MARCH 1967**

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AIR FORCE ARMAMENT LABORATORY
RESEARCH AND TECHNOLOGY DIVISION
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EGLIN AIR FORCE BASE, FLORIDA

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## FOREWORD

This report was prepared at Atlantic Research Corporation under Contract AF 08(635)-5915 for the Air Force Armament Laboratory (ATCC), Eglin Air Force Base, Florida. The work described herein was performed during the period 23 May 1966 through 23 September 1966. Program monitor was Mr. Morris Miller, AFATL (ATCC).

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# ABSTRACT

A flame bomb for high-altitude aircraft delivery from the SUU-24/A dispenser was designed and developed to minimize cratering effects and to provide maximum effective dispersion of the flame fuel. The flame fuel (napalm-B type) is contained in eight[1] frangible plastic cases, approximately 1 gallon each, which are packaged in the standard CBU-27 canister. After the canister is dropped from the dispenser it is opened at a predetermined altitude and the bombs are deployed over the target. On impact, the bomb cases shatter, dispersing the flame fuel which is ignited by breakage of a vial of triethylaluminum. Safety tests showed that inadvertent fracture of an igniter vial within a filled bomb or accidental dropping of a loaded CBU-27 canister would not result in ignition. Bombs subjected to environmental testing in canisters functioned properly when impacting at terminal velocity after a 700-foot drop. Additional drops of single bombs at 700 feet and loaded canisters at 1000 feet were all successful. Eighteen units were delivered to the Air Force for flight tests.

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[1] Six bombs and two inert spacers were used for expediency throughout this program.

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# INTRODUCTION

The Air Force currently requires a flame weapon system which can be effectively delivered from high-altitude aircraft. Present weapon systems which impact on the target at a high incidence angle at terminal velocity have a tendency to crater, especially in soft terrain. Under this program, Atlantic Research has undertaken to develop and demonstrate feasibility of a flame weapon which will minimize the cratering effect and has the following desirable characteristics:

- Maximum effective dispersion of the flame fuel without orientation or explosive dissemination.
- Compatibility with existing aircraft dispensers (SUU-24/A).
- Increased target hit probability because of the increased number of bombs per dispenser.
- Reproducible ballistics and target impact patterns.
- Reliable and inexpensive due to simplicity of system.
- Suitability for high-rate production with minimum use of critical materials and industries.

Atlantic Research Corporation has successfully developed and proven the feasibility of a flame weapon which satisfies these characteristics. This weapon system consists of eight[1] small cubical, frangible plastic bombs contained in an existing canister, the CBU-27. The loaded canister in turn is housed in the SUU-24/A dispenser mounted in the aircraft.

The thin-walled, plastic bombs satisfy the requirements of creating minimum cratering and reproducible patterns from a vertical impact at terminal velocity. As a result of impact momentum, natural dispersion of the flame fuel occurs. The safety requirements are met by packaging the frangible bombs into a closed, metal container, the CBU-27 canister. After release from the SUU-24/A dispenser, the canister is opened by the standard timer-actuated device at a predetermined altitude above the target. Thus, deployment and, therefore, ballistics of the bombs can be controlled.

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[1] Six bombs and two inert spacers were used throughout this feasibility program; see page 8.

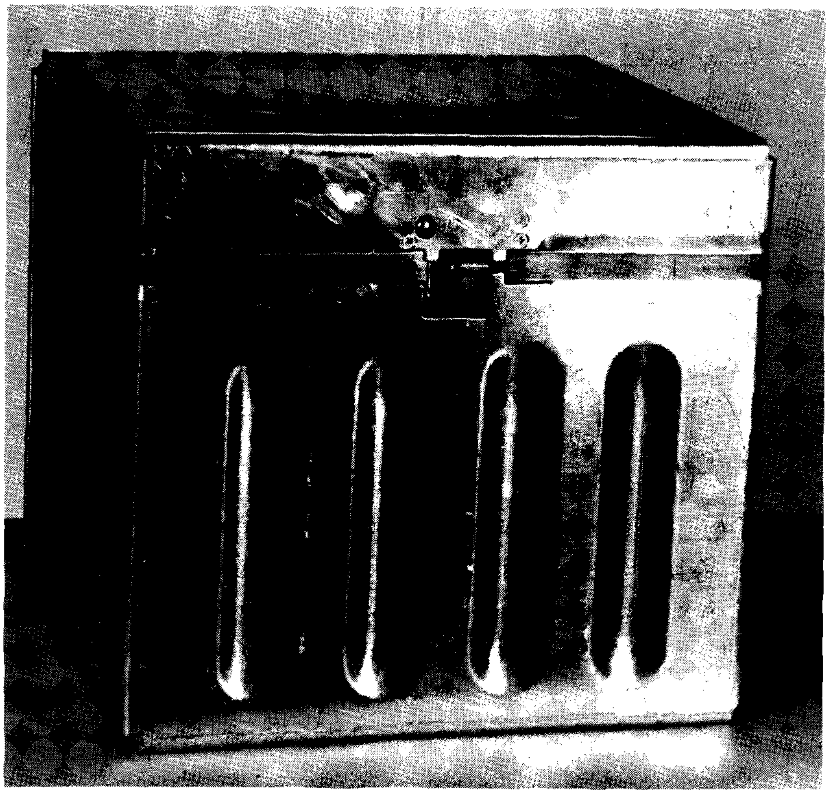
A glass vial of triethylaluminum (TEA) contained within each bomb provides a means of igniting the flame fuel. On impact, the igniter vial breaks and exposure to air ignites the TEA and subsequently the napalm-benzene vapor interface to provide overall ignition. Ignition occurred in 100 per cent of the bombs dropped, demonstrating the reliability of this type of ignition as well as the feasibility of the frangible bomb system. The simplicity of the bomb and the use of plastic and glass to contain the flame fuel and igniter make this system very adaptable to high-rate production using nonessential materials.

Table I contains a summary of the physical characteristics of the system. Figure 1 shows a view of the loaded system. A cross section of the flame bomb is shown in Figure 2.

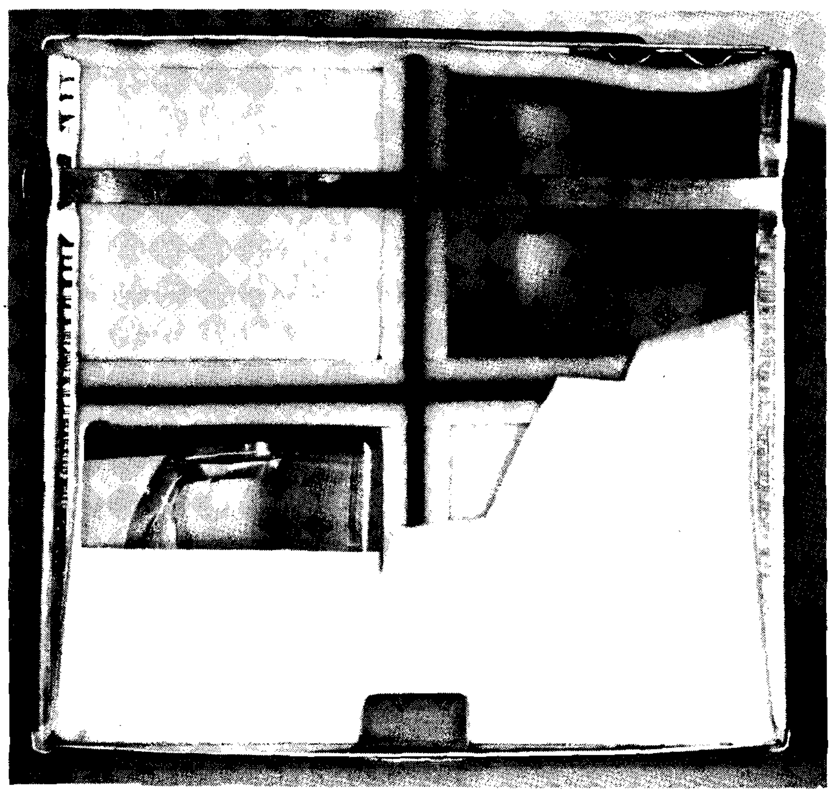
Table I. Physical Characteristics of SUU-24 Cluster Flame Bomb System.

| | |
|---|---|
| FLAME BOMB | |
| Dimensions (in) | 5.6 x 6.4 x 6.4 |
| Case material | Acetal thermoplastic |
| Case weight (lb) | 0.7 |
| Flame fuel | Napalm B[a] |
| Flame fuel weight (lb) | 6.2 |
| Igniter material | Triethylaluminum (0.13 lb) |
| Igniter weight (lb) | 0.3 |
| Total weight (lb) | 7.2 |
| CBU PACKAGE | |
| Dimension (in) | 13.2 x 14.4 x 14.4 |
| Weight, CBU (lb) | 13 |
| Packing material (lb) | 1.4 |
| Bombs (8) (lb) | 57.3 |
| Total weight (lb) | 71.7 |
| FLAME CHARACTERISTICS (per module) | |
| Flame fuel (BTU) | 112,200 |
| Igniter (BTU) | 2,380 |
| Case (BTU) | 5,180 |
| Total (BTU) | 119,760 |

[a]All references in this report to napalm or napalm B in the developed munition refer to the 44 per cent polystyrene mix as described on page 18.



a. External View.



b. Cutaway View.

Figure 1. Loaded CBU-27 Canister.

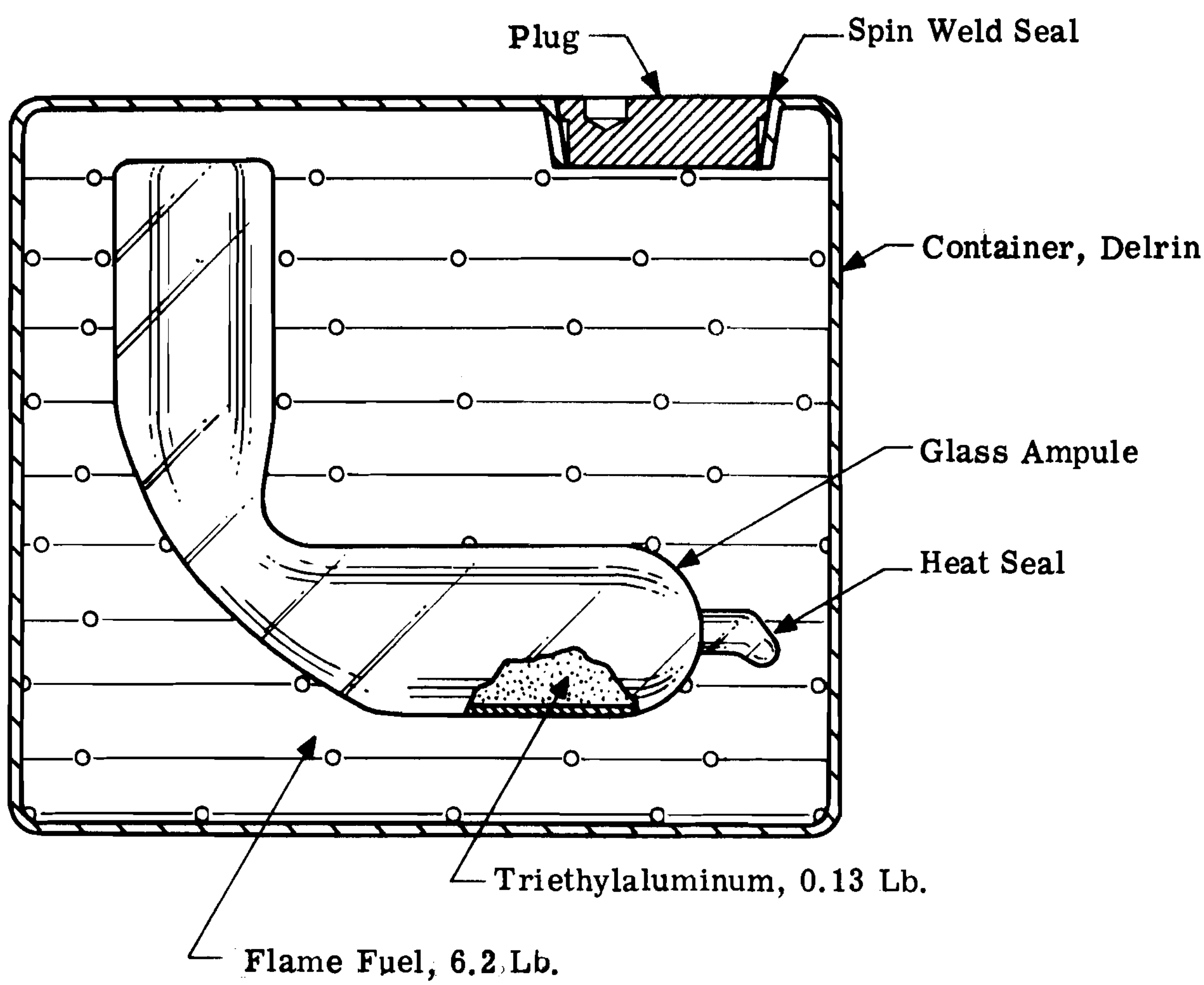



Figure 2. Cross Section of Flame Bomb.

## SECTION II

## SUMMARY

The design and development of a flame weapon system was undertaken to meet Air Force requirements for a system which can be delivered from high-altitude aircraft. The system was required to minimize the cratering effect in soft terrain, as associated with present flame weapons, and provide maximum effective dispersion of the flame fuel.

A small (approximately one-gallon size) cubical-shaped bomb case was designed to be sufficiently frangible so that impacting on soft targets would not result in cratering. To provide protection of the frangible bombs when exposed to environmental and handling loads, the bombs were packaged within the standard CBU-27 canister. Each canister holds eight[1] bombs. A divider, padded with polyurethane foam, was added to provide further protection. The units safely passed ten-foot drop tests onto concrete.

The one-piece cases were fabricated of Delrin[2] plastic using a rotational molding process. A machined Delrin plug, spin welded into a tapered fill port, was used to seal the case after loading. The wall thickness of the final configuration was established by target impact and safety drop tests. Based upon the stress analysis and burst pressure tests, the strength provided by this wall thickness yields a factor of safety greater than two.

The optimum flame fuel formulation to achieve dispersion and area coverage without cratering was established by full-scale impact tests. A napalm-B fuel formulation with a viscosity of 18,500 centipoise at room temperature provided the most effective target coverage.

A glass vial containing a pyrophoric material, triethylaluminum, (TEA), was designed for igniting the flame fuel during impact dispersion. Triethylaluminum was selected as the ignition material because of its ability to burn vigorously in air, react violently with water and for its rheological properties. An igniter vial configuration having a 90-degree bend was selected after experimentally evaluating several designs. The igniter vial is inserted into the fill port after fuel loading. No supports or orientation of the vial are required for

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[1] Six bombs and two inert spacers were used during this program. See page 8 for reason.

[2] E. I. duPont de Nemours' tradename for an acetal monopolymer resin.

safety protection or ignition reliability. Safety tests indicate that an igniter vial fractured in napalm-B does not cause ignition, thus providing a fail-safe igniter system.

A series of helicopter drop tests was conducted using inert bombs to determine the range of cratering and dispersion effects using different case wall thicknesses and napalm-B viscosities. Further drop tests of live bombs were made to establish igniter reliability and bomb performance. These tests included bombs thermally conditioned to 150°F and -30°F. Approximately 100 bombs were dropped from 700 feet and five loaded CBU-27 systems were dropped from 1000 feet. Ignition occurred on every test, and the overall flame fuel ignition efficiency was greater than 90 per cent. Maximum penetration into soft sand and soil was two inches.

Environmental tests per MIL-STD-810A were conducted at Roanoke Laboratories of TRW, Inc., on three loaded CBU-27 canisters. The tests included high temperature, low temperature, altitude-temperature, vibration, sand and dust, temperature-humidity, and salt fog. Porosity in the Delrin cases resulted in overpressurization of three bombs during altitude-temperature testing in the first environmental test series. The porosity problem was solved and improved cases were molded. The second group of 3 loaded CBU-27's were environmentally tested without failure. Bombs taken from each of the CBU-27's functioned properly when dropped 700 feet from a helicopter.

The development portion of the program was completed with the delivery of 18 loaded canisters to Eglin Air Force Base, Florida. The feasibility of the clustered frangible bomb, frangible TEA igniter system for high altitude delivery was successfully demonstrated. Further development work is recommended to optimize the present system and extend the basic concepts to fulfill other requirements.

## SECTION III

## DESIGN AND PRELIMINARY TESTING

### 1. BOMB CASE DEVELOPMENT

The basic shape and dimensions of the bomb case shown in Figure 3 were designed to allow eight of these units to be fitted into the CBU-27 canister, allowing for packaging material and divider. Two cases in each canister of a modified design are required to allow for the timing mechanism located in the upper middle of one side of the canister. The modified case design is shown in Figure 4. Modified cases were not fabricated during this program. Wooden mock-ups were used to simulate the two cases during testing.

Delrin plastic, an acetal resin product of E. I. duPont de Nemours and Company, Inc., was selected as the case material because of its physical characteristics, compatibility with benzene, and good fabrication and impact characteristics. Delrin also is a very good flame fuel itself. The properties of Delrin are summarized in Table II, and its resistance to chemicals is shown in Table III.

Several techniques for fabricating the Delrin cases were investigated. These included injection molding, rotational molding, and folding and welding sheet stock. Rotational molding, or rotamolding, was selected over the other methods. This technique involves slowly rotating a hollow mold containing a quantity of powdered resin in a controlled-temperature oven. The resin melts during rotation and adheres uniformly to the walls of the mold. After the resin has melted, the mold is cooled down and opened, and the molded case is extracted.

A unique feature of this method is that it is very simple to vary the wall thickness of the case without changing the mold configuration. Wall thickness is determined by the amount of ground resin placed in the mold prior to heating.

Other advantages of this molding technique are:

- A one-piece case can be molded.
- Molds are simple, inexpensive, and can be fabricated with a short lead time.
- Physical properties of rotamolded Delrin are comparable to those obtained by injection molding.

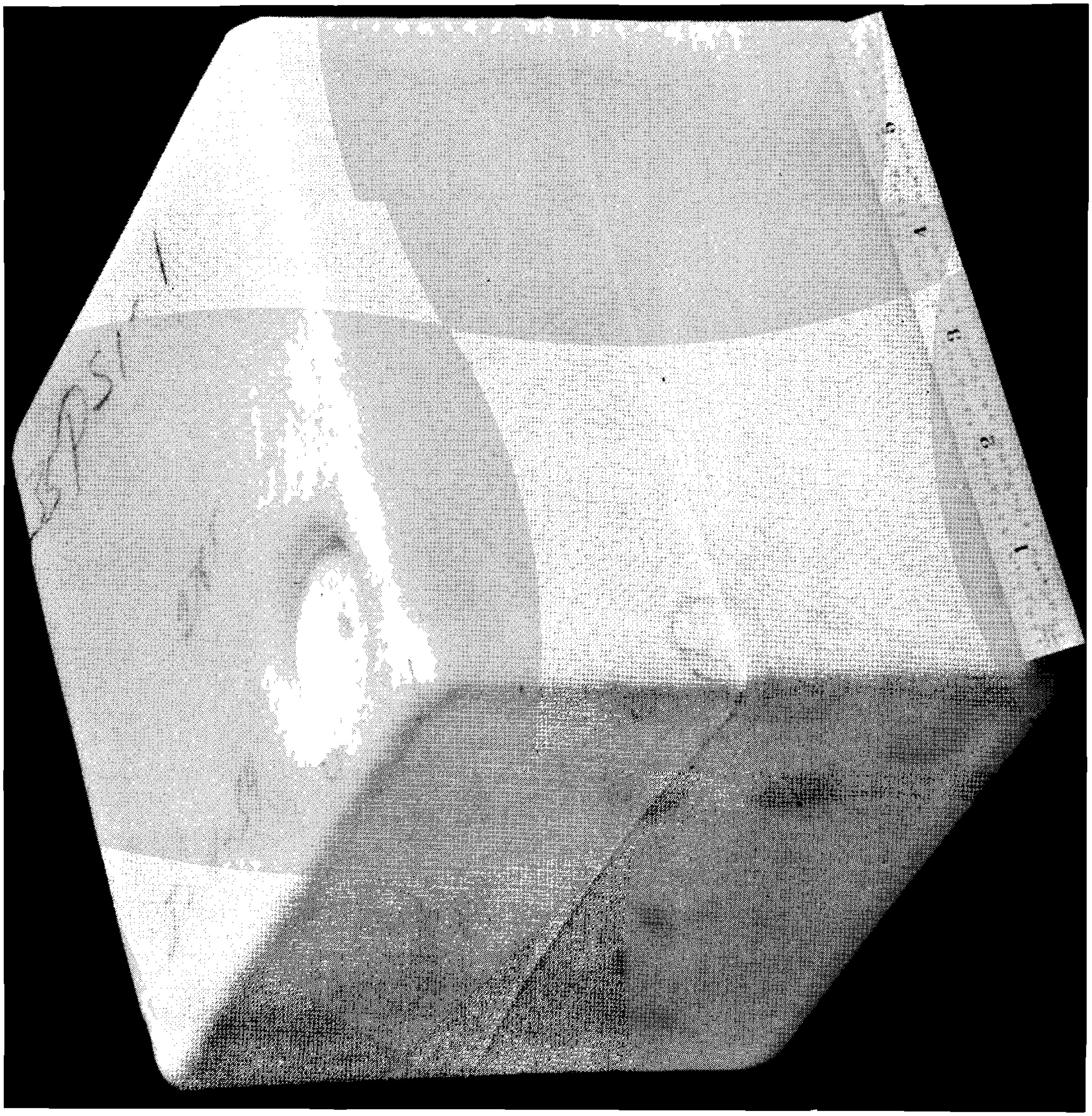


Figure 3. Bomb Case.

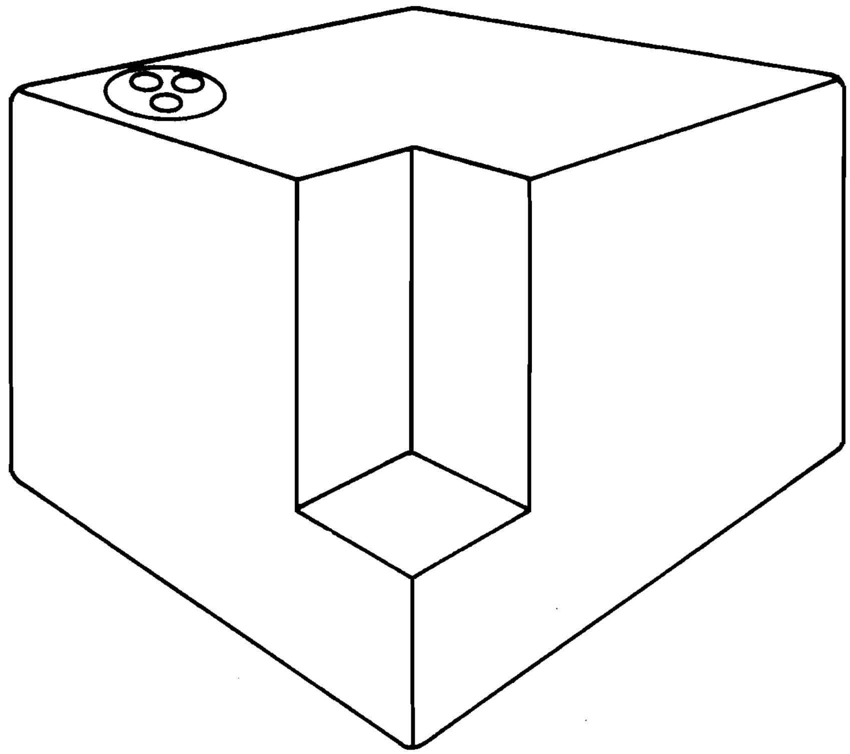


Figure 4. Modified Bomb Case.

Table II. Summary of Properties of Delrin 500.[a]

| | | |
|---|---|---|
| Impact strength, izod (ft lb/in) | -40°F | 1.2 |
| | 73°F | 1.4 |
| Tensile strength (psi) | -68°F | 14,700 |
| | 73°F | 10,000 |
| | 158°F | 7,500 |
| Flexural yield strength (psi) | | 14,100 |
| Flexural modulus (psi) | 73°F | 410,000 |
| | 170°F | 190,000 |
| | 250°F | 90,000 |
| Compressive stress (psi) | 1% deformation | 5,200 |
| | 10% deformation | 18,000 |
| Deformation under load (%) | 2000 psi at 122°F | 0.5 |
| Melting point (crystalline) (°F) | | 347 |
| Flow temperature (°F) | | 363 |
| Specific heat (Btu/lb/°F) | | 0.35 |
| Thermal conductivity (Btu/hr/sq ft/°F/in) | | 1.6 |
| Coefficient of linear thermal expansion (per °F) | | $4.5 \times 10^{-5}$ |
| Flammability (in/min) | | 1.1 |
| Water absorption (%) | 24 hr immersion | 0.25 |
| | equilibrium, 50% R.H., 77°F | 0.2 |
| | equilibrium immersion 77°F | 0.9 |
| Rockwell hardness | | M 94, R120 |
| Specific gravity | | 1.425 |
| Poisson's ratio | | 0.35 |
| Heat of combustion (Btu/lb) | | 7,400 |

[a] Delrin Acetal Resins - Design and Engineering Data, Plastics Department, E. I. duPont de Nemours and Company, Inc.

Table III. Chemical Resistance Tests on Delrin.[a]

| Material | Test Conditions | | | | Test Results | | | |
|---|---|---|---|---|---|---|---|---|
| | Conc. (%) | Test Length (days) | Test Temperature (°F) | Test Temperature (°C) | Tensile Modulus (% Change) | Tensile Strength (% Change) | Length (% Change) | Weight (% Change) |
| Acetic acid | 80 | 90 | 140 | 60 | U | U | U | U |
| Acetone | 100 | 365 | 73 | 23 | -32 | -5 | +0.9 | +4.9 |
| Acetone | 100 | 10 | 140 | 60 | -- | -5.9 | -- | +3.3 |
| Air | | 350 | 185 | 85 | -- | 0 | -- | -4 |
| Ammonium chloride | 10 | 275 | 140 | 60 | -16 | +2 | +0.1 | +3 |
| Ammonium hydroxide | 10 | 90 | 73 | 23 | U | U | U | U |
| Aniline | 100 | 275 | 140 | 60 | -67 | -12 | +0.3 | +8.3 |
| Benzene | 100 | 275 | 140 | 60 | -49 | -11 | +2.2 | +4 |
| Butyraldehyde | 100 | 275 | 140 | 60 | -49 | -12 | +1.8 | +3.0 |
| Butylamine | 100 | 90 | 140 | 60 | U | U | U | U |
| Butyl carbitol | 100 | 28 | 130 | 55 | -- | 0 | -- | -- |
| Calcium hydroxide | 0.1 | 275 | 140 | 60 | -6 | +1 | +0.4 | +0.7 |
| Carbon tetrachloride | 100 | 365 | 73 | 23 | -14 | -3 | +0.3 | +1.3 |
| 'Chlorothene' | 100 | 7 | 130 | 55 | -- | -7.8 | -- | -- |
| Dioxane | 100 | 275 | 140 | 60 | -59 | -13 | +2.7 | +6 |
| Dimethyl formamide | 100 | 275 | 140 | 60 | -7.3 | +0.6 | 0 | -0.2 |
| Ethanol | 100 | 365 | 73 | 23 | -33 | -5 | +0.8 | +2.2 |
| Ethyl acetate | 100 | 365 | 73 | 23 | -40 | -7 | +1.4 | +2.7 |
| Formic acid | 100 | 90 | 140 | 60 | U | U | U | U |

[a] Delrin Acetal Resins - Design and Engineering Data, Plastics Department, E. I. DuPont de Nemours and Company, Inc.

Table III. (continued)

| Material | Conc. (%) | Test Length (days) | Test Temperature (°F) | Test Temperature (°C) | Tensile Modulus (% Change) | Tensile Strength (% Change) | Length (% Change) | Weight (% Change) |
|---|---|---|---|---|---|---|---|---|
| | Test Conditions | | | | Test Results | | | |
| Gasoline | | | | | | | | |
| Iso-octane | 100 | 820 | 73 | 23 | 0 | -3 | +0.1 | +0.2 |
| Esso regular | 100 | 820 | 73 | 23 | -12 | -4 | +0.2 | +0.7 |
| Sunoco | 100 | 820 | 73 | 23 | -16 | -6 | +0.3 | +0.8 |
| Esso high-test | 100 | 820 | 73 | 23 | -17 | -7 | +0.4 | +0.9 |
| Hexane | 100 | 275 | 140 | 60 | -9 | -4 | +0.6 | +0.7 |
| Hydrochloric acid | 10 | 90 | 73 | 23 | U | U | U | U |
| Hydrogen peroxide | 90 | 28 | 85 | 29 | U | U | U | U |
| 'Igepal' | 50 | 365 | 73 | 23 | -2 | +2 | +0.1 | -0.2 |
| 'Igepal' | 50 | 180 | 158 | 70 | U | U | U | U |
| Isoamyl alcohol | 100 | 275 | 140 | 60 | -32 | -4 | +1.2 | +2 |
| Kerosene | 100 | 275 | 140 | 60 | -4 | 0 | +0.1 | 0 |
| Lithium chloride | 43 | 275 | 140 | 60 | -2 | +2 | +0.3 | -2.6 |
| Methanol | 100 | 275 | 140 | 60 | -41 | -10 | +1.4 | +2.3 |
| Methyl ethyl ketone | 100 | 7 | 130 | 55 | -- | -11.5 | -- | -- |
| Nitric acid | 10 | 275 | 75 | 24 | U | U | U | U |
| 'Nujol' | 100 | 365 | 73 | 23 | +10 | +1 | -0.1 | +0.3 |
| Oil - Esso 'Uniflo' 10W30 | 100 | 365 | 158 | 70 | +2 | +3 | -0.3 | -0.2 |
| Phenol | 100 | 90 | 140 | 60 | U | U | U | U |
| Perclene® | 100 | 275 | 140 | 60 | -43 | -7 | +1.6 | +5.6 |

Table III. (continued)

| Material | Conc. (%) | Test Length (days) | Test Temperature (°F) | Test Temperature (°C) | Tensile Modulus (% Change) | Tensile Strength (% Change) | Length (% Change) | Weight (% Change) |
|---|---|---|---|---|---|---|---|---|
| | Test Conditions | | | | Test Results | | | |
| Phosphoric acid | 10 | 90 | 140 | 60 | U | U | U | U |
| Potassium permanganate | 10 | 275 | 140 | 60 | -14 | 0 | +0.3 | -7 |
| Pyridene | 100 | 275 | 140 | 60 | -57 | -9 | +2.7 | +6 |
| Sodium bromate | 14 | 4 | 73 | 23 | -- | -- | -- | -1.3 |
| Sea water | 100 | 361 | 73 | 23 | -- | -4 | -- | -- |
| Sodium chloride | 10 | 365 | 73 | 23 | +20 | +3 | 0 | -0.1 |
| Sodium hydroxide | 10 | 365 | 73 | 23 | -40 | +2 | -0.1 | -0.7 |
| Commercial bleach (sodium hypochlorite) | 5 | 30 | 73 | 23 | U | U | U | U |
| Sodium thiosulfate | 26 | 275 | 140 | 60 | -31 | -18 | +0.3 | -3 |
| Sulfuric acid | 1 | 316 | 95 | 35 | U | U | U | U |
| Tetrahydrofuran | 100 | 17 | 73 | 23 | -- | -- | +0.4 | -- |
| Toluene | 100 | 365 | 73 | 23 | -45 | -7 | +1.2 | +2.6 |
| Toluene | 100 | 10 | 140 | 60 | -- | -7 | -- | +2.8 |
| Triethylamine | 100 | 275 | 140 | 60 | -41 | -19 | 0 | -4.3 |
| Triton X-100 | 100 | 275 | 140 | 60 | -13 | 0 | +0.5 | +0.3 |
| Water | | | | | | | | |
| Buffer pH 7.0 | | 365 | 158 | 70 | -12 | -20 | +0.1 | -0.9 |
| Buffer pH 4.0 | | 90 | 158 | 70 | U | U | U | U |
| Buffer pH 10.0 | | 365 | 158 | 70 | -17 | -20 | 0 | -5.5 |
| Distilled | | 275 | 140 | 60 | -18 | +2 | +0.5 | +1.5 |

KEY: U—Unsatisfactory

Stress analysis, pressure testing, and impact tests were used to determine the optimum wall thickness. The stress analysis, presented in Appendix I, indicates that a wall thickness of 0.045 inch would withstand the required 35 psi internal pressure at ambient temperature and rupture very easily at impact velocities of 150 feet per second. The 35 psig internal pressure is created by the thermal expansion of the fuel when loaded to 90 per cent full in a sealed container. Pressure tests indicated a minimum case burst pressure of 50 psi for the 0.045-inch wall.

Test cases with wall thicknesses varying from 0.030 to 0.080 inch were loaded with flame fuel and dropped 500 feet from a helicopter. These tests were performed to determine the effect of wall thickness on cratering and flame fuel dispersion. Wall thickness up to 0.080 inch was found to have a negligible effect on these parameters, and the 0.080-inch wall was selected to provide an increased safety factor for handling of the bomb. The final bomb case configuration weighs 0.7 pound.

A 1-5/8-inch diameter, 10-degree tapered fill port was molded into one corner of the case. A Delrin plug, shown in Figure 5, is spin welded into the port to seal the case after it is filled. Spin welding simply involves rotating the cap under a force and at a speed which will melt the interface between the cap and the tapered hole. After the interface has cooled, a complete seal around the cap is achieved. A drill press fitted with a simple adapter is used to spin weld the cap in place. The port was located near the corner to gain added structural support required for the spin welding process.

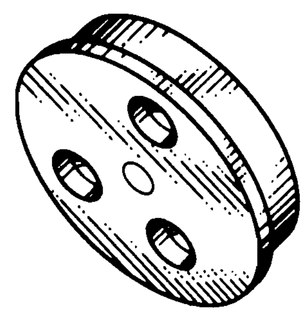


Figure 5. Fill Plug.

A porosity problem occurred in the first group of molded cases. This problem results in the failure of a case during environmental testing, discussed further under Section IV and Appendix II. The basic cause of the porosity was resin contamination introduced during the grinding process. Improved resin grinding and handling procedures were established to eliminate porosity. In addition, cast aluminum molds were substituted for the fabricated sheet molds and the molding cycles were altered, both of which resulted in increased quality cases.

## 2. IGNITION SYSTEM

The system selected for igniting the flame fuel after target impact consists of a hermetically-sealed glass vial containing triethylaluminum, a pyrophoric liquid.

Glass was chosen for the igniter vial for several reasons:

- Nonreactant with pyrophoric materials.
- Compatible with hydrocarbon flame fuels.

- Filling and hermetic sealing of glass containers in controlled environments is a common process.
- Inexpensive and readily available.
- Physical properties are well known.
- Fracture characteristics of glass are desirable for a frangible system.

Several glass vial configurations were evaluated for igniter use. These included standard, straight 50-milliliter glass ampules; straight ampules with ballooned, thin wall sections; and ampules with a 90-degree bend. Breaker weights inside the ampules were also evaluated. During testing, napalm-B was found to produce sufficient cushioning of the igniter vial at impact that orientation of the straight-tube configuration was required to achieve fracture. The 90-degree bend configuration, shown in Figure 6, was found to eliminate the need for orientation, and it provided 100 per cent breakup on all subsequent impacts.

It had originally been planned to isolate the glass igniter vial from the bomb body by means of suspension springs attached to each end of the vial. Testing showed, however, that the viscous flame fuel provided a sufficient cushioning effect to prevent accidental igniter breakage. The igniter is allowed to float in the flame fuel, thus reducing the complexity and number of bomb components. This arrangement performed well during the vibration phase of environmental testing, with no igniter breakage occurring. The fracture of an igniter vial within a bomb was studied and is discussed in Section IV.

Triethylaluminum was selected for use as the ignition material because it was desirable to have a liquid material which flows with the impact momentum and does not require an auxiliary dispersion force. TEA burns vigorously in air and reacts violently with water. Eutectic white phosphorus had been considered for use as an ignition material but was ruled out because it does not burn in water. Reaction with water is an important consideration when the flame bomb may be used in areas where a considerable percentage of land is under water and moisture and humidity are prevalent.

TEA is readily available, fully characterized, relatively inexpensive, and has been used in other military flame applications. It is a stable, clear, colorless liquid, with the chemical composition of $(C_2H_5)_3Al$. The specific gravity of TEA is 0.835 at 25°F, and it has a very low vapor pressure (2 mm of Hg at 75°C) and a low freezing point (-50°F). The viscosity of TEA over the operating temperature range (-30°F to 150°F) is low which permits simple dissemination.

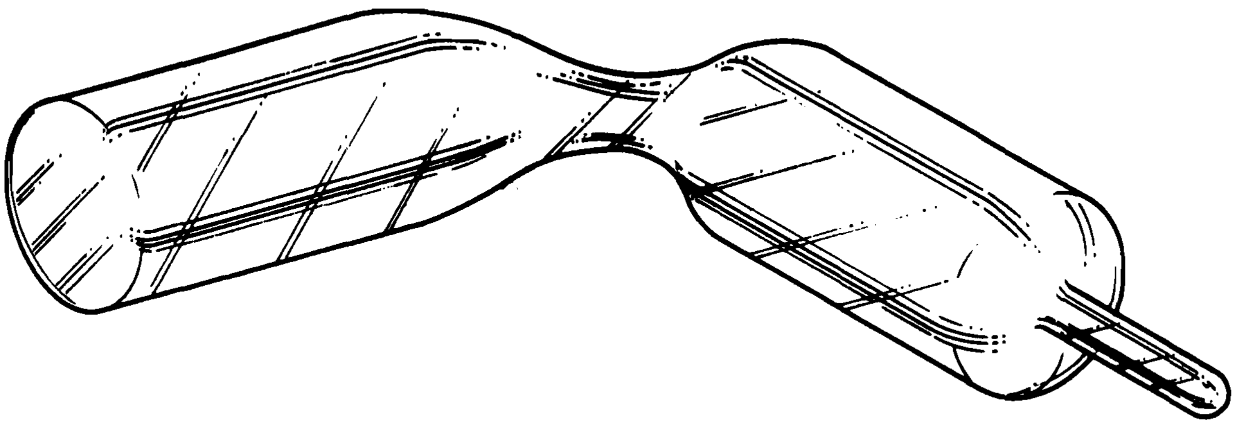


Figure 6. Igniter.

Dissemination is achieved by pressurizing the filled vial with butane. Butane is compatible with TEA and also aids in ignition of napalm-B. The igniter vials are 60 per cent filled with 0.13 pound of TEA and butane to avoid overpressurization at the high temperatures. Loaded vials were conditioned to 180°F without failure.

## 3. FLAME FUEL

A napalm-B type flame fuel was chosen for use with this bomb system because of its overall superiority as an all-purpose fuel and because its rheological properties are well suited for the mode of impact dissemination. Three modified formulations were prepared to determine the optimum viscosity of napalm-B for the breakup characteristics of the Delrin case. These formulations are shown below:

| | 1 | 2 | 3 |
|---|---|---|---|
| Polystyrene (per cent) | 46 | 38.5 | 31.75 |
| Benzene | 21 | 30.75 | 43.25 |
| Gasoline | 33 | 30.75 | 25 |
| Viscosity (centipoise) | 26,480 | 5,020 | 1,750 |

Impact tests showed that the lowest viscosity formulation, No. 3, broke up into very fine particles; formulation No. 2 produced small strings on dispersion; and the most viscous formulation, No. 1, produced a limited sheet covering. The photographs in Figure 7 show the results of using these formulations in bombs dropped from a helicopter. The area coverage of formulation No. 3 cannot be seen because of the fine particles and, therefore, photographs of these tests are not included.

Based on the impact test results, it was decided to use a formulation somewhere between the 5,000 and 26,000 centipoise viscosity. The formulation below was selected:

| | |
|---|---|
| Polystyrene (per cent) | 44 |
| Benzene | 21.8 |
| Gasoline | 34.2 |

a. Formulation Number 1.

b. Formulation Number 2.

Figure 7. Dispersion Tests - Agent Viscosity Study.

A 2400-pound batch of this formulation was then mixed in the horizontal mixing facility. The average viscosity of the batch was 18,500 centipoise. Impact tests with this formulation indicated negligible cratering and sufficient dispersion to effectively cover the maximum area for the quantity of fuel (6.2 pounds), approximately 400 square feet.

## 4. PACKAGING

It was initially planned to cushion the bomb cases in the CBU-27 canister with a foam-type cushioning material to prevent the bombs from damaging each other or the canister during handling. This was done with polyurethane foam in one canister, and a ten-foot drop test was made. Considerable breakup of the cases, igniters, and canister occurred. A modified packaging system was designed to provide additional support. It consists of a plywood[1] divider, see Figure 8, with thin layers of polyurethane foam. The divider serves as a rigid member to support the walls of the canister, and it provides an even distribution of load surface for the flat sides of the bomb cases.

Additional live drop tests were made using the divider system, and damage was considerably reduced, and no ignition occurred. See Figure 9 for results of the second series of ten-foot drop tests. Aircraft drop tests were also conducted, and the divider had no adverse effect on deployment of the bombs when the canister was opened during free-fall.

[1]Plywood was selected for use in this program for convenience; the future material selection will be subject to optimization studies.

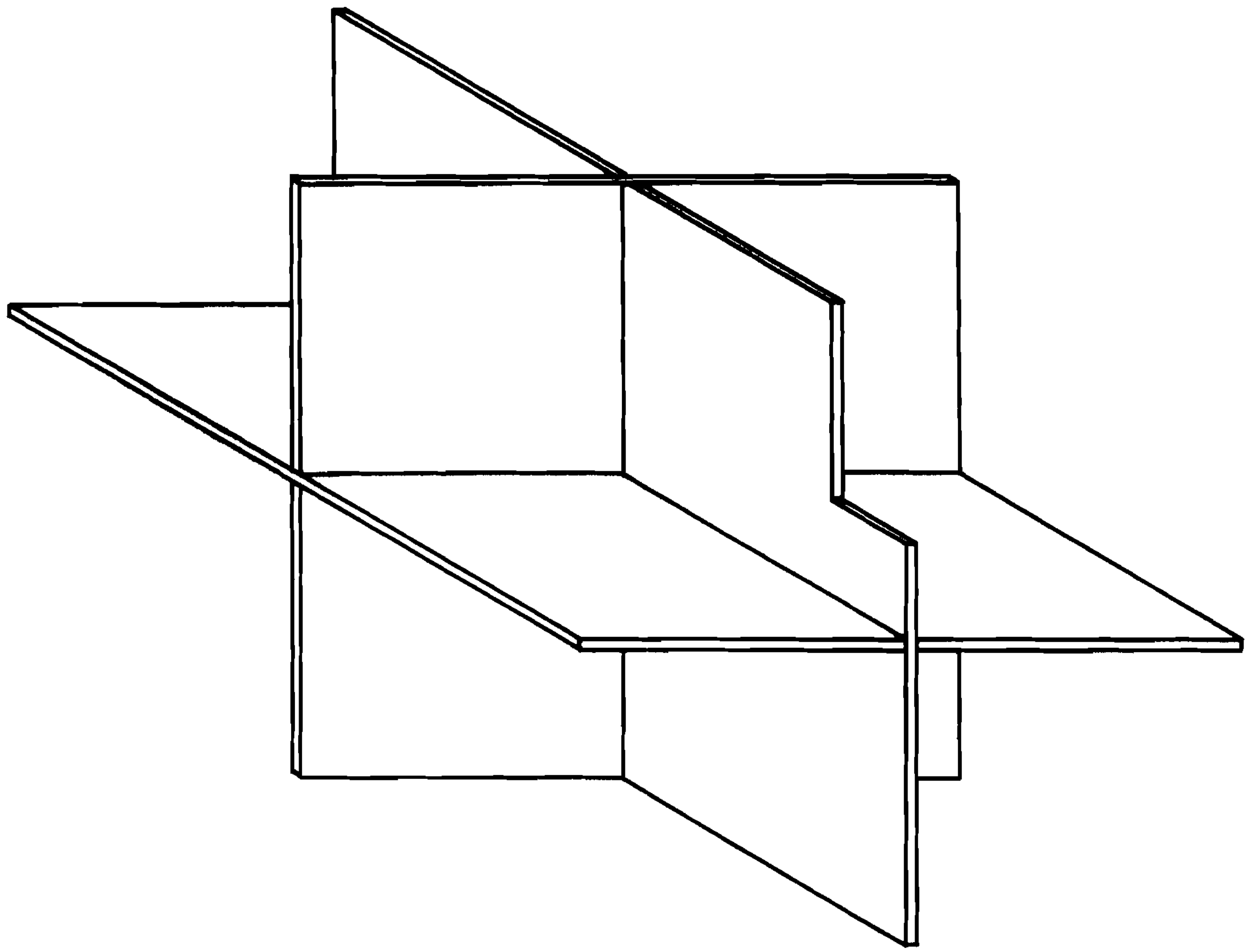
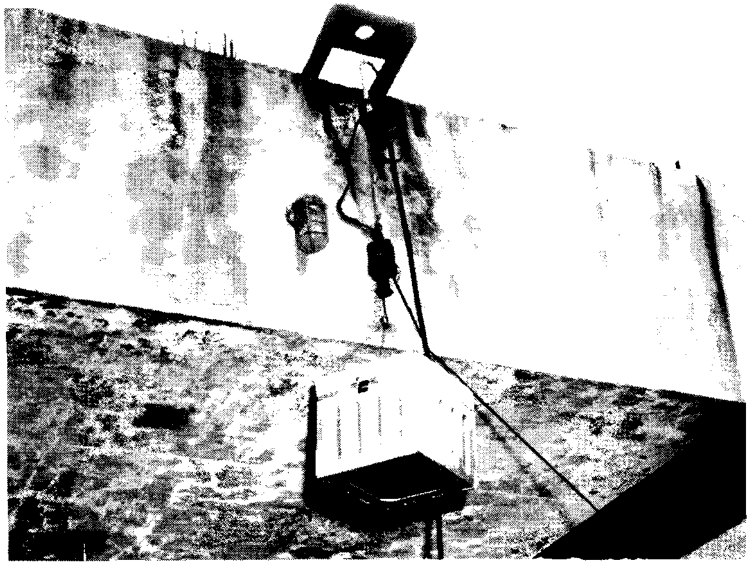


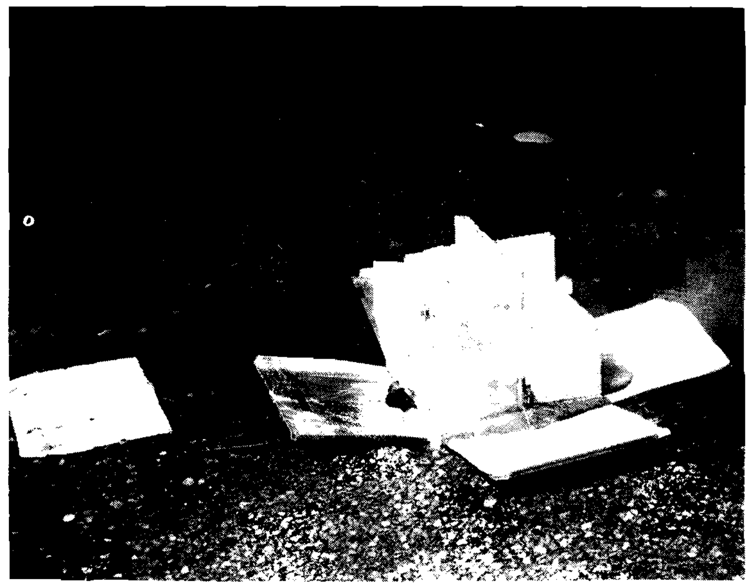
Figure 8. Divider for CBU-27.



a. Drop Test Setup.

b. CBU-27 After Drop.

c. CBU-27 Showing Agent Leakage.



d. Open CBU-27 Showing Bomb Damage.

Figure 9. Results of 10-Foot Drop Test.

## SECTION IV

## QUALIFICATION TESTING

### 1. SAFETY TESTS

#### a. Igniter Fracture

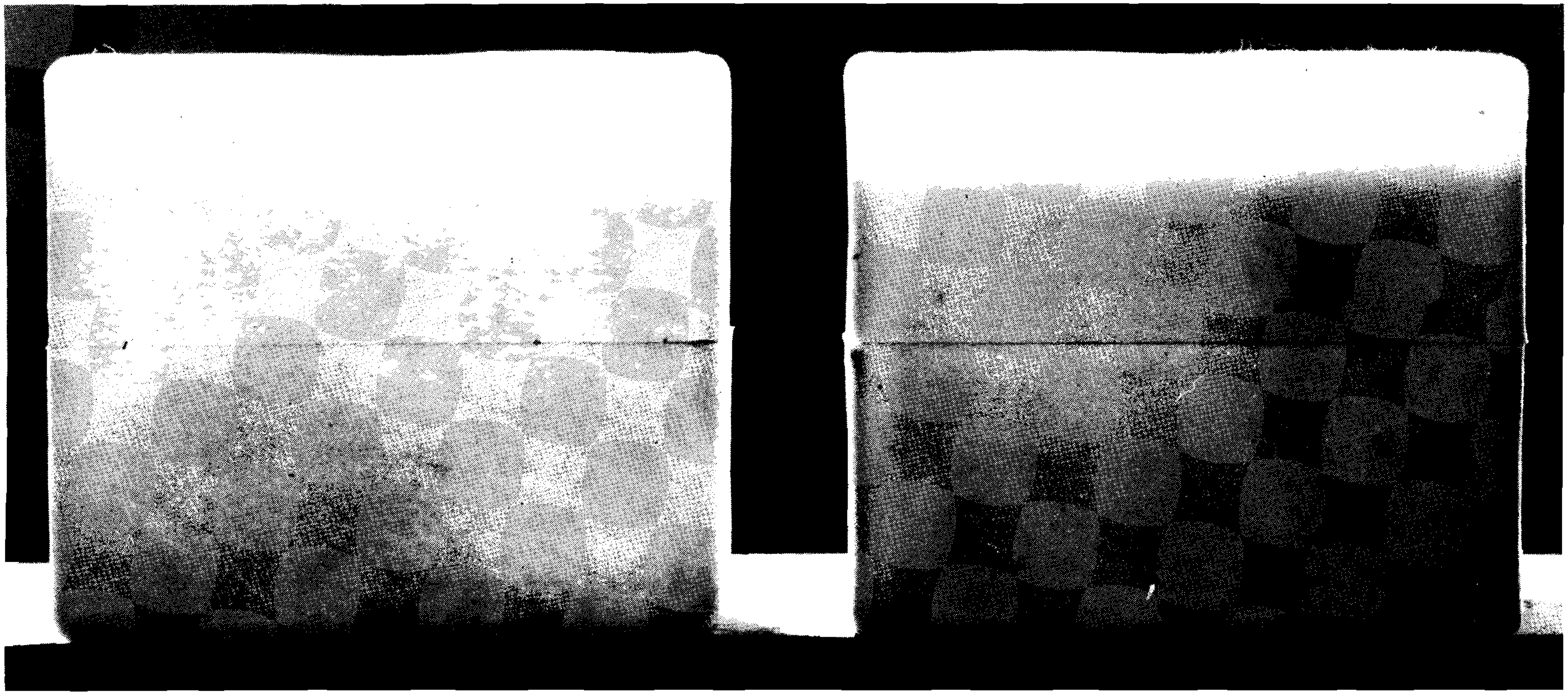
One of the principal concerns with the bomb system is accidental fracture of the igniter vial within the Delrin case during handling. Although it is difficult to cause accidental fracture because of the cushioning effects of the flame fuel, several tests of igniter vial fracture within napalm-B were performed to demonstrate the igniter fail-safe characteristics. When an igniter vial is broken in napalm-B, the triethylaluminum does not cause ignition for two reasons: (1) the pyrophoric properties of TEA are neutralized by the benzene component of napalm-B; and (2) TEA, which has not yet been neutralized, is slowly released from the napalm-B and does not generate sufficient heat to cause ignition.

Igniters were broken within the napalm-B in open flat pans, in filled Delrin cases with the top removed, and in filled Delrin cases which were sealed. In the first two cases, the TEA fumed and released aluminum oxide smoke, but no ignition occurred. In one sealed Delrin case fracture test, there was enough heat generated from the oxidation of TEA to open a small hole in the case and permit the gases to escape. The results of the igniter fracture tests are shown in scenes on the motion film delivered to Eglin Air Force Base as part of this program.

It was found that it is possible to visually check the loaded Delrin cases to determine if inadvertent igniter fracture has occurred. When a case containing a broken igniter is viewed against a strong light, a mottled surface, as shown in Figure 10, is seen, indicating the presence of aluminum oxide. Although inadvertent igniter fracture has never occurred, the possibility of occurrence has not been overlooked. Defective bombs can be easily detected using the above technique and withdrawn from use.

#### b. Drop Tests

The other major safety test performed was a ten-foot drop test of a loaded CBU-27 canister onto solid concrete. This test simulates inadvertent release of the bomb from the SUU-24 dispenser in an aircraft onto the concrete taxi strip or runway. The bombs are not required to be operational after this test, but ignition cannot occur.



a. Igniter Broken

b. Unbroken Igniter.

Figure 10. Comparison of Cases With and Without Broken Igniters.

Two loaded CBU-27 canisters were dropped ten feet onto reinforced concrete. In both tests, bomb cases were broken and several igniter vials were fractured. Small amounts of napalm-B ran from the corners of the canisters[1] onto the concrete, and some smoking occurred, but ignition did not occur (see Figure 9). The units were opened after an interval of five and ten minutes to determine if ignition would occur when the broken igniters and cases were exposed; ignition did not occur. In order to determine if fire would spread due to subsequent fracturing of vials or flow of flame fuel, a complete canister was set on fire. The fire was contained in the unit itself and did not spread over any appreciable area. The drop tests and the canister fire were also covered in the movie film delivered to Eglin Air Force Base.

## 2. PERFORMANCE TESTS

Inert bombs were used in preliminary performance tests to determine the range of cratering and dispersion characteristics which are achieved with different wall thicknesses of Delrin and viscosities of napalm-B. The results of these tests are shown in Table IV and Figure 7. Igniter configuration, case wall thickness, and fuel viscosity were established from these tests as discussed previously. The single bomb drop tests were performed from a helicopter flying at a 500-foot altitude.

After the design parameters had been established, 82 single bombs were drop tested from a 700-foot altitude, which is sufficient in height to attain terminal velocity prior to impact. The bombs impacted on soft sod, loose sand, freshly plowed earth, and gravel to establish cratering characteristics, dispersal pattern and igniter reliability. A series of the bombs was conditioned to 150°F and -30°F.

In all of these tests, undesirable cratering did not occur; maximum penetration into the soft targets was two inches. Ignition occurred on every live drop test. Approximately 90 to 95 per cent of the fuel was ignited and consumed. The burn time was 12 to 17 minutes at ambient conditions, 5 to 7 minutes at 150°F, and 25 to 45 minutes at -30°F. The average pattern was a square 30 to 50 feet on a side, at both ambient conditions and 150°F. Although the flame fuel within the bombs conditioned to -30°F appeared to be frozen, ignition occurred on these tests. A 2- to 3-foot dispersal pattern occurred after ignition. Figure 11 illustrates the dispersion obtained from a -30°F (and +150°F) inert (flame fuel with no igniter) drop.

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[1] A modified version of the CBU-27, with reinforced corner structures, is expected to further reduce damage during drop. The new version was not available for this program.

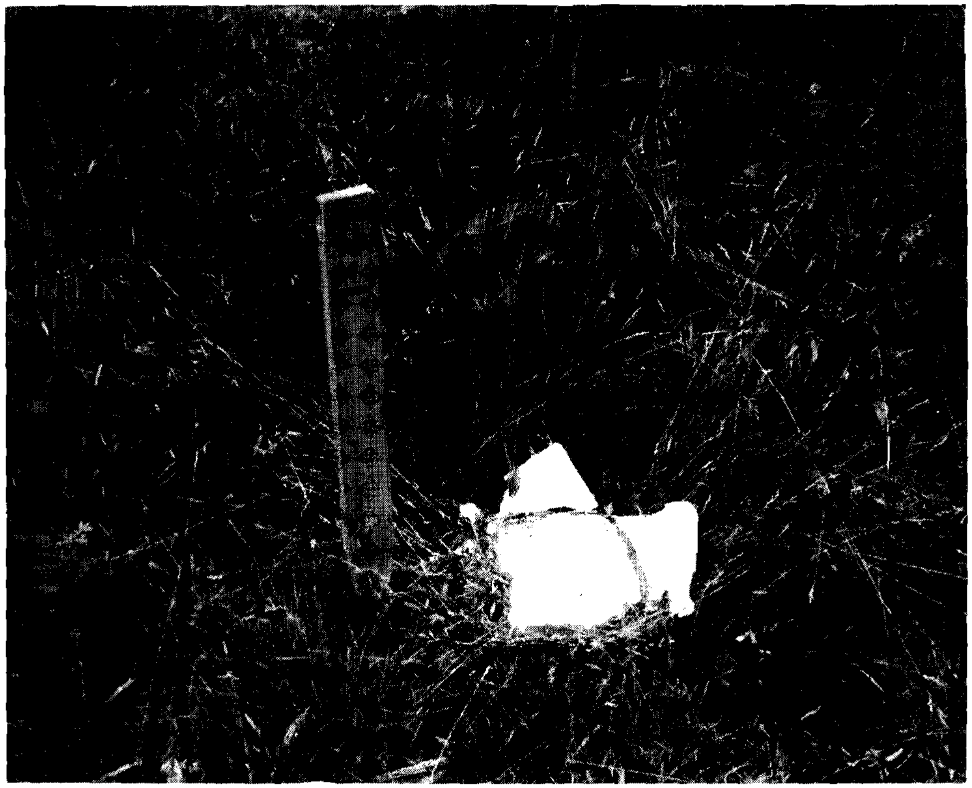
Table IV. Summary of Dispersion Test Results.

| Test Items: | | | | Test Results: | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Case | | | | | Crater | | Fuel | |
| Test No. | Wall (in) | Flame Fuel | Igniter Vial | Impact Surface | Igniter Break | Depth (in) | Dia. (in) | Raduis (ft) | Dispersal Comment |
| T-1 | 0.030 | B | S.V. | sod | no | 1 to 1.5 | 10 | 5 to 6 | film |
| T-2 | 0.030 | B | L.V. | sod | no | 2 | 8 to 10 | 8 to 12 | film |
| T-3 | 0.030 | D | S.V. | sod | yes | 0.5 to 1 | 10 | 10 to 20 | strings |
| T-4 | 0.030 | D | L.V. | trees | no | -- | -- | -- | -- |
| T-5 | 0.030 | C | S.V. | plowed ground | no | 3 | 14 | 15 | fine strings |
| T-6 | 0.030 | C | L.V. | sod | no | 2 | 10 | 10 | strings |
| T-7 | 0.045 | B | S.V. | gravel | no | 3 | 18 | 8 | film |
| T-8 | 0.045 | B | L.V. | plowed ground | no | 2 | 12 | 7 to 12 | strings |
| T-9 | 0.045 | D | S.V. | plowed ground | yes | 3 | 8 | indet. | fine strings |
| T-10 | 0.045 | D | L.V. | plowed ground | yes | 2 | 12 | indet. | fine strings |
| T-11 | 0.045 | C | S.V. | plowed ground | yes | 1.5 to 2 | 12 | 6 | heavy strings |
| T-12 | 0.045 | C | L.V. | plowed ground | no | 3 | 12 | 10 | heavy strings |

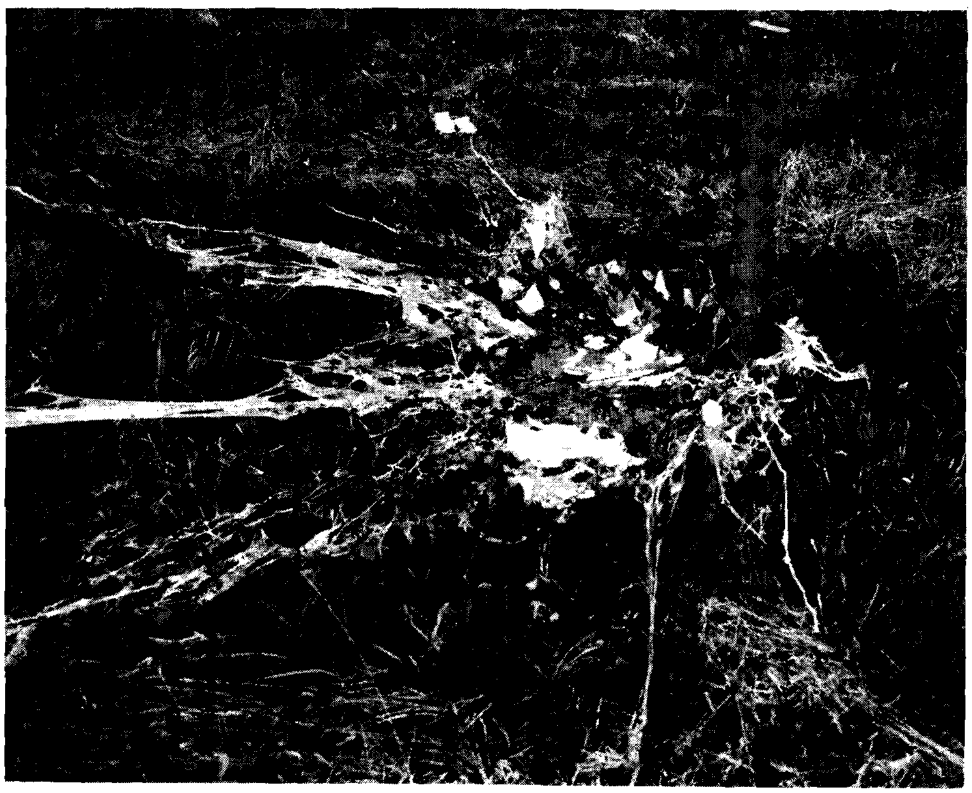
Legend:

| Flame Fuel | Formulation[a] | Viscosity |
|---|---|---|
| B | 46/21/33 | 26,480 cps |
| C | 38.5/30.75/30.75 | 5,020 cps |
| D | 31.75/43.25/25.0 | 1,750 cps |
| S.V. | Standard vial (50 ml with flat bottom) | |
| L.V. | Lengthened vial (50 ml; L/D 1.5 times S.V.) | |

[a]Formulation is given by per cent of polystyrene, benzene, and gasoline, respectively.



a. -30°F



b. 150°F

Figure 11. Dispersal Pattern at Temperature Extremes.

The configuration of the fuel coverage varied somewhat, depending upon the orientation of the bomb case at impact. The aerial shots contained in the motion film clearly show this. In general, the pattern was square, but on occasion the fuel was dispersed in two distinct directions (180 degrees apart). In the latter case, dispersion would extend approximately 100 feet from tip to tip. The overall effect of these pattern variations are considered negligible in light of the large number of bombs which will be released simultaneously, consequently no orientation devices were incorporated. When large numbers of bombs impact a target area, sufficient overlapping and crossover will occur to adequately cover the entire area.

In addition to the single bomb tests, five drop tests were conducted on loaded CBU-27 canisters. The objective of these tests was to demonstrate satisfactory deployment of the bombs from the canister and determine the results of an impact test in which the CBU does not function. The units were released from a 1000-foot altitude from a single engine aircraft and impacted on a soft, loose sand target area. One inert unit was used for trajectory determination and four live units were dropped, two intact and two timed-opening.

The latter units were timed to open at approximately 500-foot altitude. The bombs were satisfactorily deployed from the canister and each bomb ignited upon impact. Although these tests were not designed to establish bomb pattern because of the low-altitude release, the resultant impact pattern resulted in complete area coverage. Bombs were spaced approximately 25 feet apart.

Of the two units which were dropped intact, one unit missed the target area and dropped into the ocean resulting in no usable test data. The second unit impacted the sand target and provided approximately the same area coverage as the deployed system. The length and width of the pattern (25 feet by 150 feet) were significantly different, however, and a large amount of the fuel remained at the center of the impact. The results of this test demonstrate that a loaded CBU with a malfunctioning timer will still provide significant target destruct, although the dispersal pattern and area coverage are less than the deployed system. It is interesting to note that the crater created by this unit was also insignificant (3 to 4-inch depth by 20-inch diameter).

Figure 12 contains results of the loaded CBU drop tests. The results of all drop tests are clearly shown in the motion film.

a. Detail of Flame Fuel Dispersion.

b. View of Impact Area.

Figure 12. Results of Loaded CBU Drops on a Sand Surface.

## 3. ENVIRONMENTAL TESTS

Three loaded CBU-27 canisters were subjected to the environmental test sequence as shown in Table V. Environmental tests started on 17 July 1966 at Roanoke Laboratories, TRW Inc., Roanoke, Virginia. The three loaded canisters successfully passed the high temperature and low temperature tests. After the altitude-temperature test, it was noted that flame fuel was flowing from the corner of one of the canisters. This unit was opened, and it was found that one of the Delrin cases, shown in Figure 13, had failed from an overpressure. There were also two additional units that had positive internal pressure. This canister was removed from the testing, and the two remaining canisters were subjected to the remaining environmental testing before terminating the test series. Both units passed vibration testing successfully with no case or igniter failures.

The cause of overpressurization in the bomb was determined to be porosity within the Delrin case. The overpressuring failure was reproduced in the laboratory using test cases containing small holes. It was found that temperature cycling would cause ambient air to be drawn into the case during the cold cycle, and during the hot cycle expansion of the napalm-B would seal the hole causing an overpressuring effect. This conclusion was further verified by analyzing the gases in the pressurized bomb and comparing to the gases in an unpressurized bomb.

The second group of three CBU-27's were loaded with improved bomb cases and sent to Roanoke Laboratories for a second complete environmental test series. Each canister was opened, and all bombs were inspected after the completion of each test. No failures or signs of weakness of any bomb or igniter were noted during any phase of the environmental test. The environmental test reports from Roanoke Laboratories are included in this report as Appendices II and III.

The three loaded canisters were returned to Atlantic Research Corporation after completion of the tests, and two bombs were taken from each unit for performance testing. The six bombs were dropped 700 feet from a helicopter to check the ignition and dispersion characteristics. The six units functioned properly, and all igniters functioned successfully. Slight ignition delays occurred on two bombs due to a change in viscosity of the flame fuel. The viscosity change was caused by vapors escaping from an improperly sealed plug. Comparison of weights before and after environmental tests revealed an average weight loss of 2.4 per cent.

None of the timers on the second group of CBU-27's functioned properly. The timers were furnished with the CBU-27's and were not a part of this development program. The timer on Unit No. 4 would not expire

Table V. Environmental Test Sequence.

| Environmental Test Number | Sequential Treatments | Referenced Method |
|---|---|---|
| 1 | High temperature | 501.1 |
| 2 | Low temperature | 502.1 |
| 3 | Temperature-altitude (cycle) | 504.1 |
| 4 | Humidity (cycling) | 507.1 |
| 5 | Vibration | 514.1 |
| 6 | Sand and dust | 510.1 |
| 7 | Salt-fog | 509.1 |

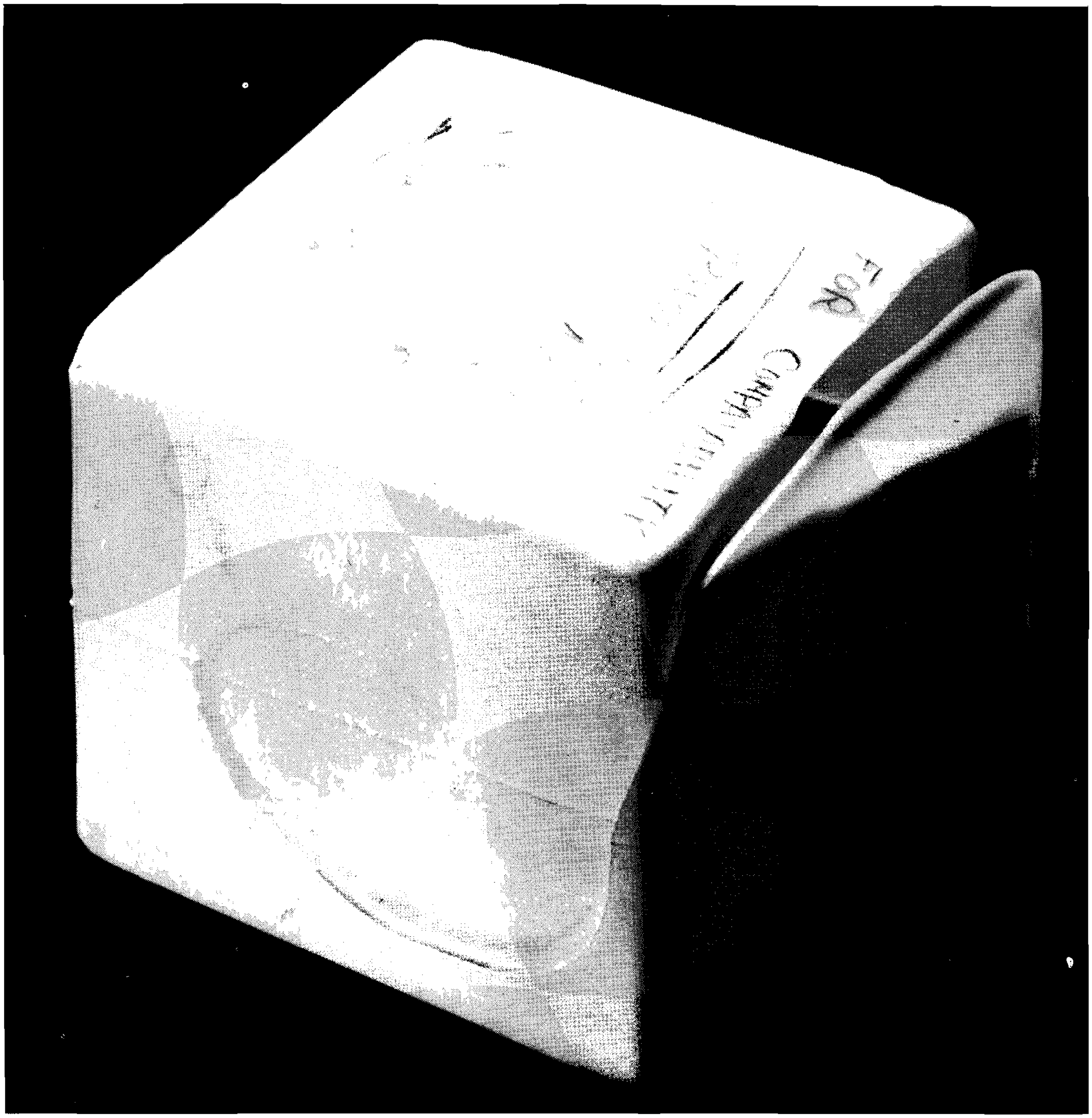



Figure 13. Overpressurized Case After Temperature - Altitude Testing.

without applying force to the mechanism. The bore rider starting pin would not pop out on Unit No. 5. The canister banding did not snap open on Unit No. 6 after the timer functioned properly. Examination of the timers indicates material corrosion, possibly due to salt fog tests, and loose parts, from vibration, are the two probable causes of the failures.

## SECTION V

## CONCLUSIONS AND RECOMMENDATIONS

On 16 September 1966, eighteen loaded CBU-27 canisters, 12 live and 6 inert, were delivered to Eglin Air Force Base, Florida. Two inert units were included at no extra cost in addition to the four inert units required by the contract. Each of the canisters contained six loaded bombs and two dummy spacers. All units were identical with the exception that the inert units contained no igniters. These units have been delivered to Eglin Air Force Base, along with the 550-foot 16 mm movie and incendiary bomb models, in compliance with the contractual requirements.

The success of this program demonstrated the feasibility of this particular type of bomb concept. The original guidelines were met quite successfully, and the system shows great promise for its application in flame-type weapons. Of prime importance is the simplicity of the system and the use of nonessential state-of-the-art materials and processes for the production of such a bomb unit. The facilities (glass blowing, plastic molding, etc.) required for production of the bomb are also relatively uninvolved in defense, thus, their participation would further increase the industrial capacity in times of emergency. Further improvement and development of the system is warranted. Such efforts as optimization of production procedures, the optimization of loading density and bomb size, and the improvement of a CBU canister unit for this bomb should be undertaken. Maximum effectiveness can be realized by utilizing a similar combustible material for the CBU structure as was used in the bomb case. The final bomb package is expected to be lower in cost, to be more effective than current systems, and to provide the previously mentioned advantages.

APPENDIX I

STRESS ANALYSIS OF DELRIN BOMB CASES

APPENDIX I

STRESS ANALYSIS OF DELRIN BOMB CASES

## 1. SUMMARY

A stress analysis was conducted on the Delrin cases to evaluate the response to an internal pressure of 35 psi and impact onto soft soil at 150 fps. Mechanical properties were determined by tensile test of specimens cut from the cases, and the average strength and elongation were found to be only two-thirds of the values reported by Du Pont.

Stress calculations using large deflection theory show that the 0.045-inch thick cases can support the internal pressure of 35 psi at ambient temperature with a factor of safety of 1.25. The maximum deflection of a side panel for this pressure is calculated to be 0.34 inch.

The energy available to rupture the cubes when they impact with sod was estimated using data furnished in NASA TND-1269. This analysis shows that a very high margin of available energy to rupture energy exists for impact velocities of 150 fps.

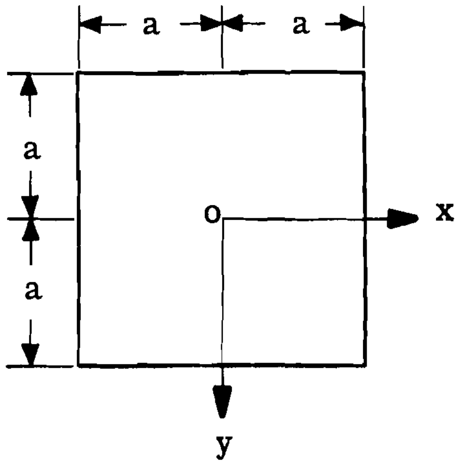
The maximum safe drop height of the bomb onto concrete was calculated to be 19 inches. Therefore, some padding or extreme care will be necessary in the assembly area.

It is concluded that the minimum wall thickness of the Delrin cases can be increased to provide better safety margins on the internal pressure and safe drop and still allow the bomb to fracture on impact of 150 fps.

## 2. ANALYSIS

### a. Internal Pressurization

The Delrin cases must be capable of sustaining an internal pressure of 35 psi without fracture. To provide a simple lightweight structure that will fracture upon impact of 150 fps, large deflection theory was used to design the case for internal pressure.




$a = 3.0$ inches

$h = 0.045$ inch

Average Delrin mechanical properties (obtained by samples cut from cases):

$F_{tu} = 6610$ psi

$E = 260{,}000$ psi

$\nu = 0.25$

The side panels are considered to be square membranes with the deformations taken as presented by Timoshenko[1] to be

$$w = w_o \cos\frac{\pi x}{2a}\cos\frac{\pi y}{2a}$$

$$u = 0.147\,\frac{w_o^2}{a}\sin\frac{\pi x}{a}\cos\frac{\pi y}{a} \tag{1}$$

$$v = 0.147\,\frac{w_o^2}{a}\cos\frac{\pi x}{a}\sin\frac{\pi y}{a}$$

The midplane strains are given in terms of the displacement as

$$\epsilon x = \frac{\partial u}{\partial x} + \frac{1}{2}\left(\frac{\partial w}{\partial x}\right)^2$$

$$\epsilon y = \frac{\partial v}{\partial y} + \frac{1}{2}\left(\frac{\partial w}{\partial y}\right)^2 \tag{2}$$

$$\gamma xy = \frac{\partial u}{\partial y} + \frac{\partial v}{\partial x} + \frac{\partial w}{\partial x}\frac{\partial w}{\partial y}$$

---

[1] Timoshenko and Woinowsky - Krieger, Theory of Plates and Shells.

and the membrane stress resultants are

$$Nx = \frac{Eh}{1-v^2} (\epsilon x + v \ \epsilon y)$$

$$Ny = \frac{Eh}{1-v^2} (\epsilon y + v \ \epsilon x) \quad (3)$$

$$Nxy = \frac{Eh}{2(1+v)} \gamma xy$$

At the boundary, x = a, the membrane forces must balance the pressure force, so that

$$8 \int_o^a Nxdy = 4q \ a^2 \quad (4)$$

Substituting Equations (1) and (2) into Equation (3), we have at x = a

$$\frac{Nx}{x = a} = \frac{0.147 \ \pi \ Eh \ w_o^2}{(1-v^2) \ a^2} \left[2.675 \cos^2 \frac{\pi y}{2a} - \cos \frac{\pi y}{2a}\right]$$

from which

$$\int_o^a Nxdy = 0.344 \ \frac{Eh \ w_o^2}{a} \equiv \frac{q \ a^2}{2}$$

therefore, rearranging gives

$$w_o = 1.206 \ a \sqrt{\frac{q \ a}{Eh}} \quad (5)$$

The membrane stress throughout the panel can be shown to be

$$\sigma m = 0.462 \ K \ \frac{E \ w_o^2}{a^2}$$

where K is presented on Figure I-1.

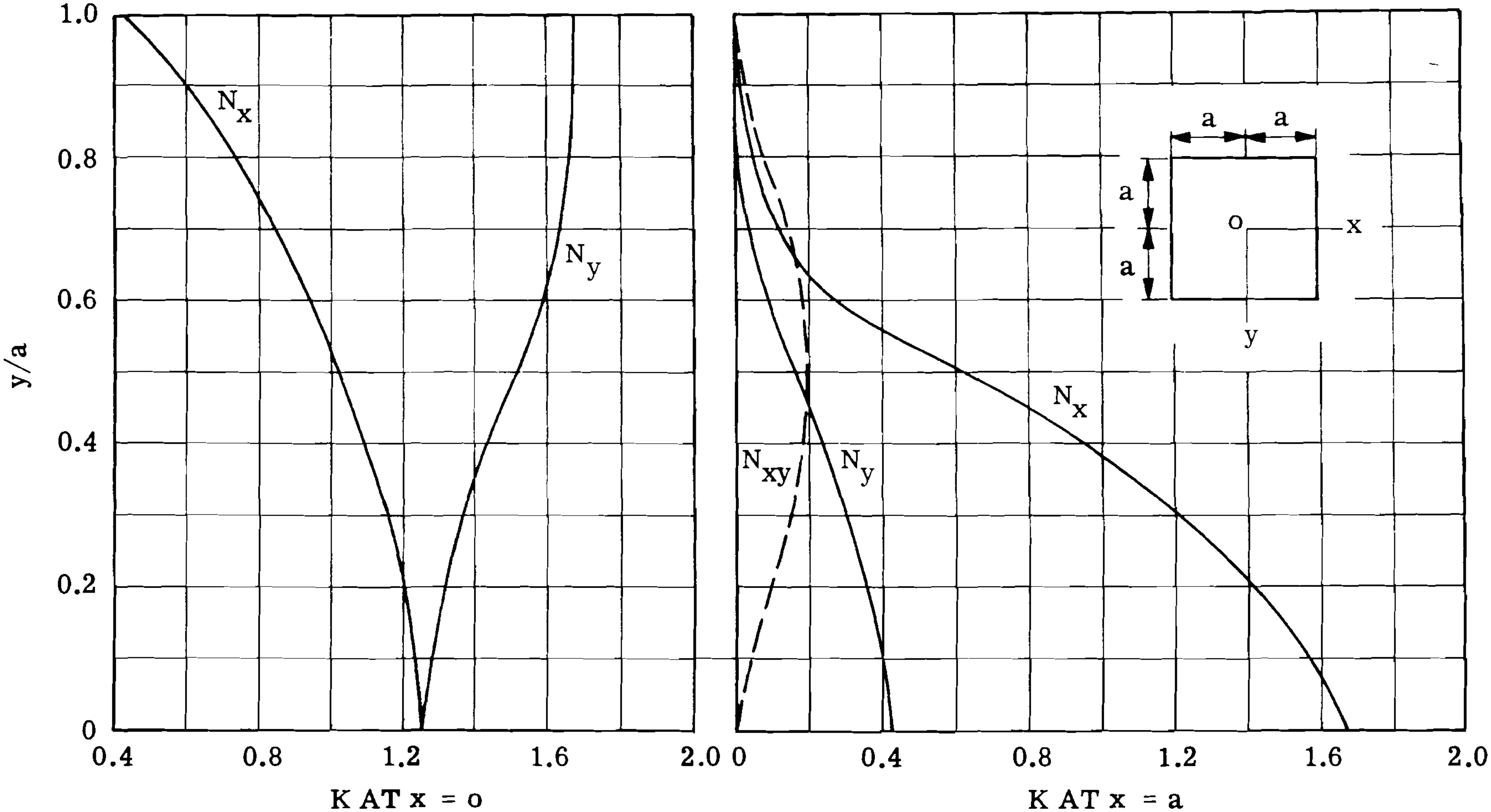



Figure I-1. Membrane Stress Distribution for Side Panels.

12199

The actual stress is evaluated by determining the amount of load supported by bending and that portion supported by membrane action. The deflection due to bending is

$$w_B = \frac{0.228\, q_B\, a^4}{Eh^3} \tag{6}$$

The normal pressure load is given by

$$q = q_m + q_B$$

or

$$4.38 \frac{Eh^3\, w_o}{a^4} \left[1 + 0.157 \left(\frac{a}{h}\right) \left(\frac{w_o}{h}\right)\right] = 35 \text{ psi}$$

Solving, the deflection-thickness ratio is

$$\frac{w_o}{h} = 7.55$$

therefore,

$$w_o = 0.34 \text{ inch}$$

Therefore, the pressure components are

$$q_m = 34.56 \text{ psi}$$

$$q_B = 0.44 \text{ psi}$$

The maximum stress occurs at x = a and y = o and is given as

$$\sigma_{max} = 1.12\, q_m \frac{a}{h} + 1.23\, q_B \frac{a^2}{h^2}$$

Figure I-2 shows the maximum stress as a function of pressure (q).

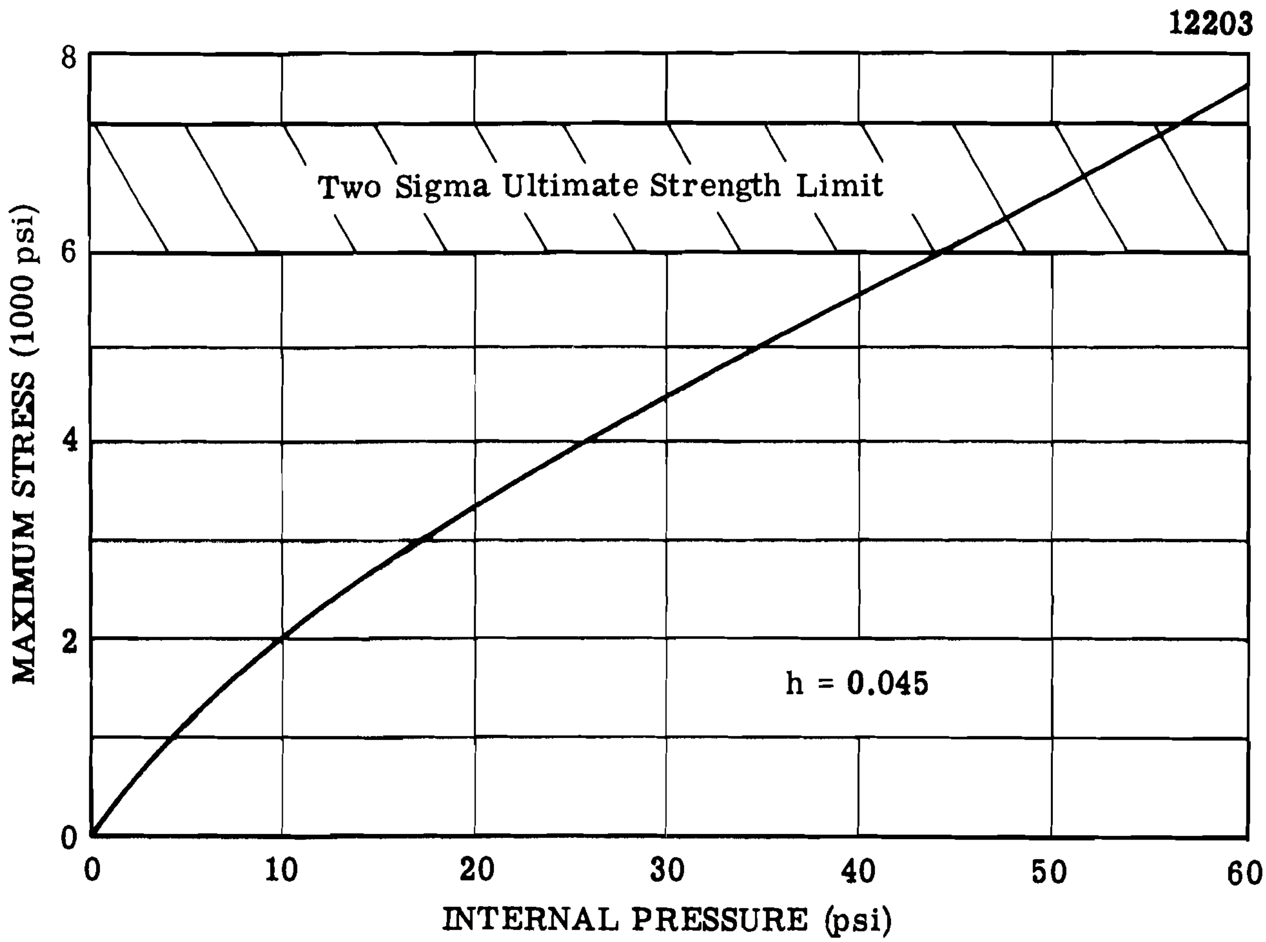



Figure I-2. Stress-Pressure Relationship.

b. Impact Loading

The energy required to rupture the cases will be compared with the available energy at impact so that the minimum height of drop onto sod which will ensure rupture can be determined.

The rupture energy for the cases is given as

$$U = \frac{f F_{tu}^2 V}{2E} \quad (7)$$

where

$F_{tu}$ = ultimate Delrin stress

$E$ = modulus of elasticity

$V$ = volume of material

$f$ = factor depending upon the stress distribution $\leq 1.0$

Use will be made of the data in NASA TND-1269[1] for impact onto sod. The impact with sod is best described as a plastic deformation process. The maximum acceleration and deformation for this process are given by the Meyer Law as

Acceleration:

$$\hat{a} = v_i \sqrt{\frac{\pi D p}{m}} \quad (8)$$

$v_i$ = impact velocity ($\sqrt{2gH} \leq 150$ fps)

$p$ = dynamic flow pressure (130 psi)[2]

$D$ = diameter of case

$m$ = mass of bomb (w/g)

[1] "Impact Characteristics of Various Materials Obtained by an Acceleration-Time-History Technique Applicable to Evaluating Remote Targets," National Aeronautics and Space Administration, June 1962, (TND-1269).

Penetration:

$$y = v_i \sqrt{\frac{m}{\pi D_p}} \tag{9}$$

The energy dissipated during the deformation of the sod will be estimated so that the energy available for rupture may be determined. The resisting force for plastic flow is

$$F = \frac{\pi D^2}{4} p \tag{10}$$

The plastic energy dissipated in deforming the sod becomes

$$Up = \frac{1}{2} F \cdot y = \frac{D}{8} \frac{\vec{a}}{g} W \tag{11}$$

Now, the available energy for rupture is

$$UA = WH \left[ 1 - \frac{1}{8} \frac{D}{H} \frac{\vec{a}}{g} \right] \tag{12}$$

$$W \doteq 6.3 \text{ lb (weight of Napalm)}$$

Two extreme conditions are considered - one for the bomb impacting on a flat side, and the other for impact on a corner. The diameters are taken as $D_1$ = 6.0 inches, and $D_2$ = 2.0 inches, respectively.

Figure I-3 shows the ratio of UA/UR as a function of height of drop. If UA/UR ≥ 1, rupture will occur. The stress factor, f, has been conservatively taken as equal to 0.75.

c. Safe Drop Height

For this condition it is assumed that all of the energy is available for rupturing the case. If we assume a stress intensity factor of

$$f = 0.15,$$

then the rupture energy for the case is

$$UR \doteq 10.0 \text{ ft-lb.}$$

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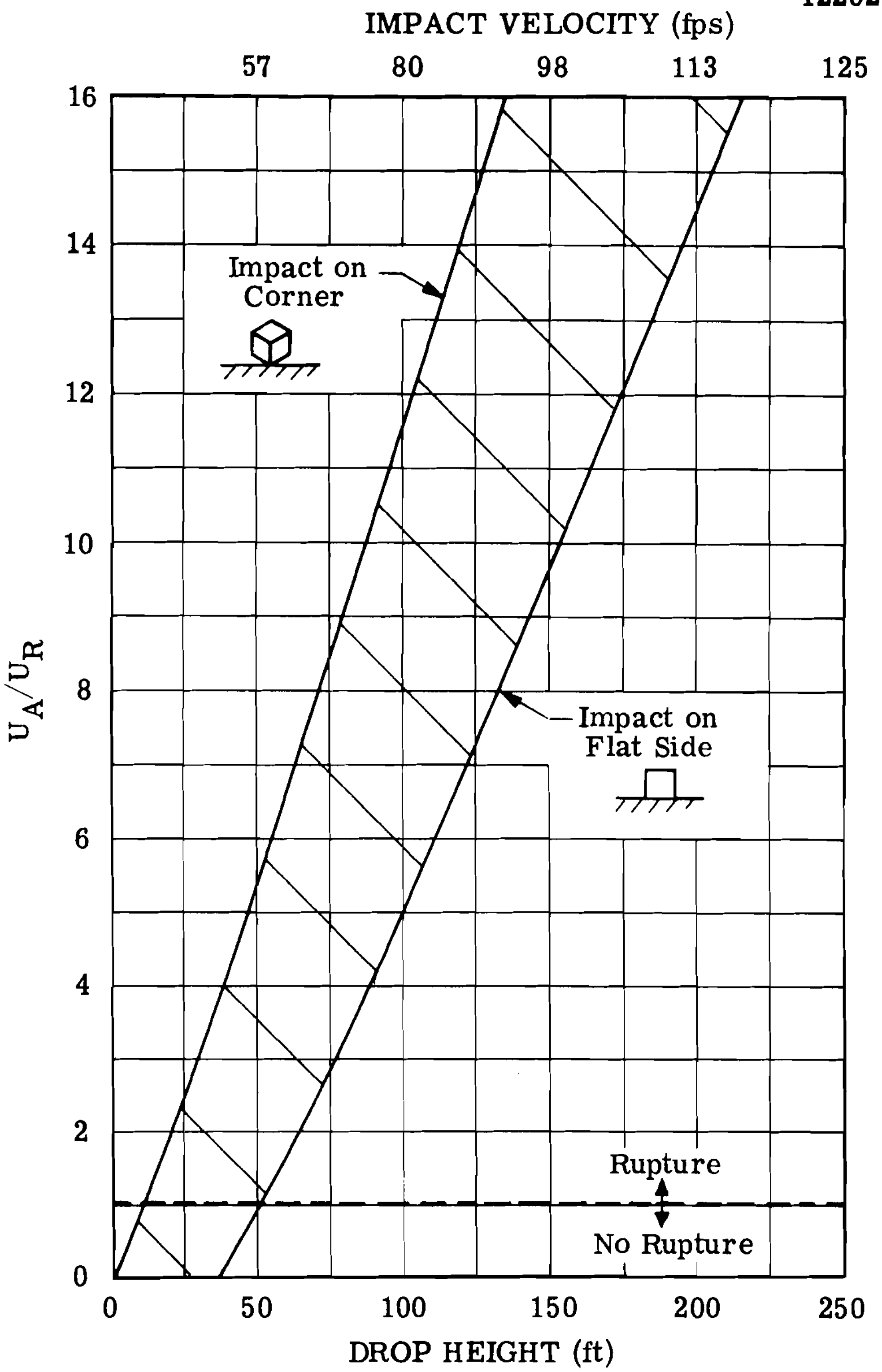


Figure I-3. Impact of Delrin Case with Sod.

With these assumptions, the safe height of drop onto concrete will be

$$Hs = \frac{UR}{W} = \frac{10.0}{6.3} = 1.59 \text{ ft}$$

or

$$HS = 19 \text{ inches.}$$

If the height of safe drop is to be increased, some form of padding will be required.



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APPENDIX II

Environmental Test Report RL 2099

for

Atlantic Research Corporation

on Flame Bombs

September 1966

TRW, Incorporated
Roanoke Laboratories
Rocky Mount, Virginia

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## LIST OF CHARTS



## LIST OF TABLES



## APPENDIX "A"

ABSTRACT

This report covers the environmental tests as listed in Table 1 performed on Atlantic Research Corporation's Incendiary Bomb, part number SUU-24A. The results of these tests are recorded in the Test Results section of this report.

Following the Temperature-Altitude cycle, one of the napalm cubes was found to have ruptured. (See photograph in Appendix "A")

A. SCOPE

This report presents the results of the environmental tests, as presented in Table I, that were performed on the Atlantic Research Corporation's Incendiary Bombs, part number SUU-24A, serial numbers 001, 002 and 003. These tests were conducted in accordance with Atlantic Research Corporation's Procedure ETS-012-82-5819.

B. TEST REQUIREMENTS

The environmental test specification specified that the individual units be subjected to the following sequence of tests.

1. High Temperature - Each unit shall be subjected to an ambient temperature of 150 degrees fahrenheit for a period of 48 hours. At the conclusion of this period, the units shall be removed from the test chamber and inspected.

2. Low Temperature - Each unit shall be placed in an ambient temperature of minus 30 degrees fahrenheit for a period of 48 hours. At the conclusion of this period, the unit shall be removed from the test chamber and inspected.

3. Temperature Cycle - Each unit shall be placed in a test chamber and subjected to the following sequential environments.

| Sequence | Temperature (F) | Altitude (ft) | Time (hr) |
|---|---|---|---|
| 1 | Ambient | Sea level | -- |
| 2 | 85 | 50,000 | 0.5 |
| 3 | 65 | 50,000 | 1.0 |
| 4 | 10 | 50,000 | 1.0 |
| 5 | -20 | 50,000 | 2.0 |
| 6 | -30 | 50,000 | 1.0 |
| 7 | 85 | Sea level | 1.0 |

At the conclusion of this test, each unit shall be inspected.

4. Vibration - Each unit shall be subjected to the sinusoidal vibration test contained in Mil-Std-810A, method 514.1, utilizing the following conditions:

Class 1
Mount A
Curve B

At the conclusion of this test, each unit shall be inspected.

C. TEST PROCEDURE

The test specimens were subjected to the following sequence of tests.

1. High Temperature

a. The test specimens were placed in the test chamber at ambient temperature.
b. Chamber temperature was increased to 150 degrees fahrenheit and stabilized.
c. A 48 hour test cycle was conducted.

2. Low Temperature

a. The test specimens were placed in the test chamber at ambient temperature.
b. The chamber temperature was reduced to minus 30 degrees fahrenheit and stabilized.
c. The stabilized temperature of minus 30 degrees fahrenheit was maintained for 24 hours.
d. The chamber temperature was returned to ambient.

3. Temperature-Altitude

a. The test specimens were installed in a vacuum temperature chamber.
b. Temperature and pressure were stabilized at ambient conditions.
c. Pressure was reduced to 50,000 feet, and a temperature of 85 degrees fahrenheit was maintained for one half hour.
d. The temperature was reduced to 65 degrees fahrenheit while the 50,000 feet altitude was maintained. These conditions were maintained for one hour.
e. The temperature was reduced to 10 degrees fahrenheit and 50,000 feet altitude was maintained. These conditions were maintained for one hour.
f. The temperature was reduced to minus 20 degrees fahrenheit, and altitude was raised to 50,000 feet. These conditions were maintained for two hours.
g. The temperature was reduced to minus 30 degrees fahrenheit, and altitude was maintained at 50,000 feet. These conditions were maintained for one hour.
h. The temperature was increased to 85 degrees fahrenheit while the pressure was returned to sea level.
i. The test specimens were removed from the chamber, and inspected by Atlantic Research Corporation personnel.

4. Vibration

   a. A sinusoidal survey was conducted from 5-500-5 cycles per second, recording the input and response accelerometers on the visicorders and magnetic tape. (See Figure 2 and Table 2)
   b. The response accelerometers were individually played back through the tracking filter and recorded on the visicorder. (See Figure 3 and Table 3)
   c. From the reproduced data, the resonant points were established.
   d. Each of the resonant points established was subjected to 30 minutes of vibration.
   e. Additional cycles were performed between 5-500-5 cycles per second at 15 minutes per cycle to provide three hours total vibration.
   f. Steps a. through e. were repeated for each of the remaining two axis.
   g. At the conclusion of vibration testing, each unit was inspected for physical failure.

D. TEST HISTORY

The following tests were conducted during the days indicated below:

| | |
|---|---|
| High Temperature | 8-4-66 to 8-6-66 |
| Low Temperature | 8-6-66 to 8-8-66 |
| Temperature-Altitude | 8-8-66 to 8-9-66 |
| Vibration | 8-19-66 to 8-22-66 |

E. TEST RESULTS

The environments of high temperature and low temperature were completed on the three units without any evidence of physical failure. At the conclusion of the temperature altitude cycle, an excess of napalm was found in the chamber. Inspection of the units showed a failed cube in unit serial number TU-1. (See photograph of failure in Appendix "A")

Data sheets of the various tests are found in Appendix "A" of this report.

12621

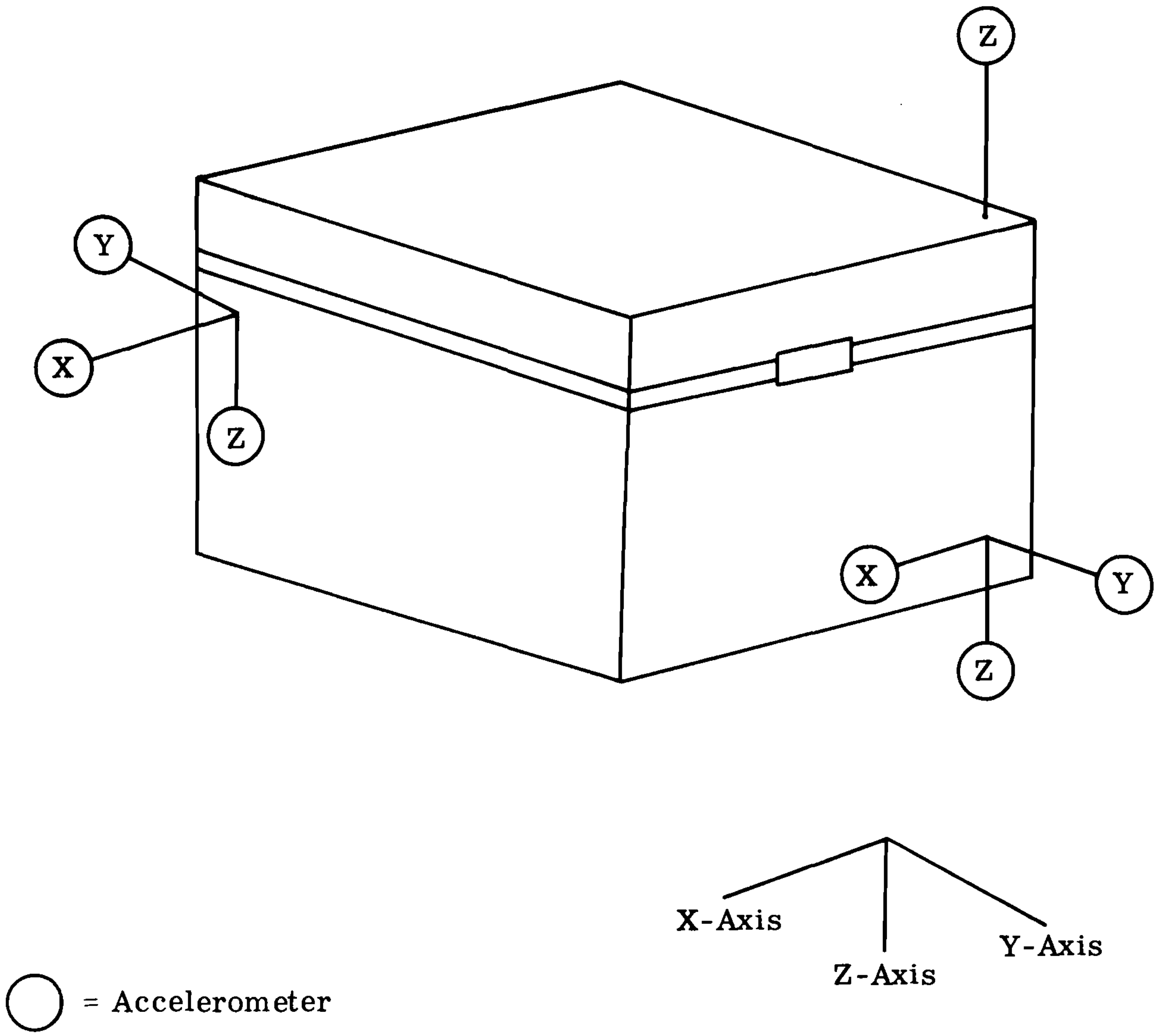
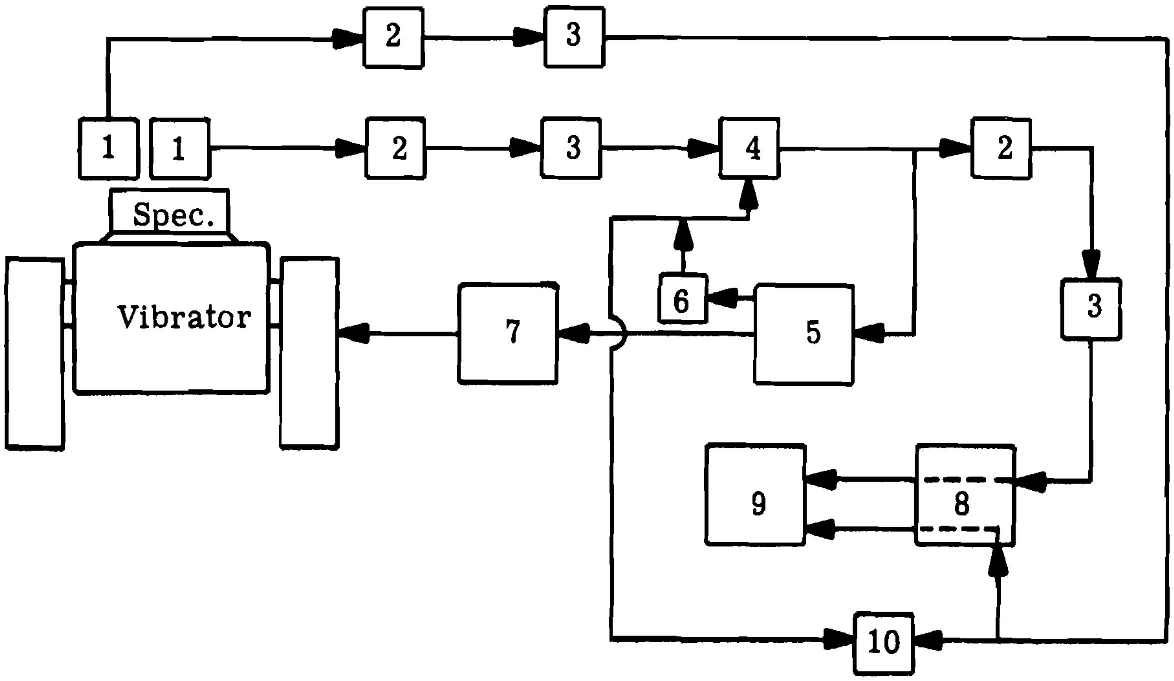


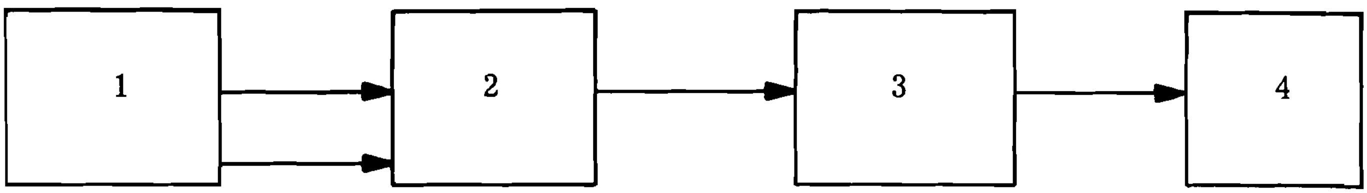

Figure 1. Axis of Vibration and Accelerometer Locations.




See Table 2 for Equipment List

Figure 2. Vibration Control and Recording Channels.

12620




See Table 3 for Equipment List

Figure 3. Tape Recorder Playback.

Table 1
Environmental Tests

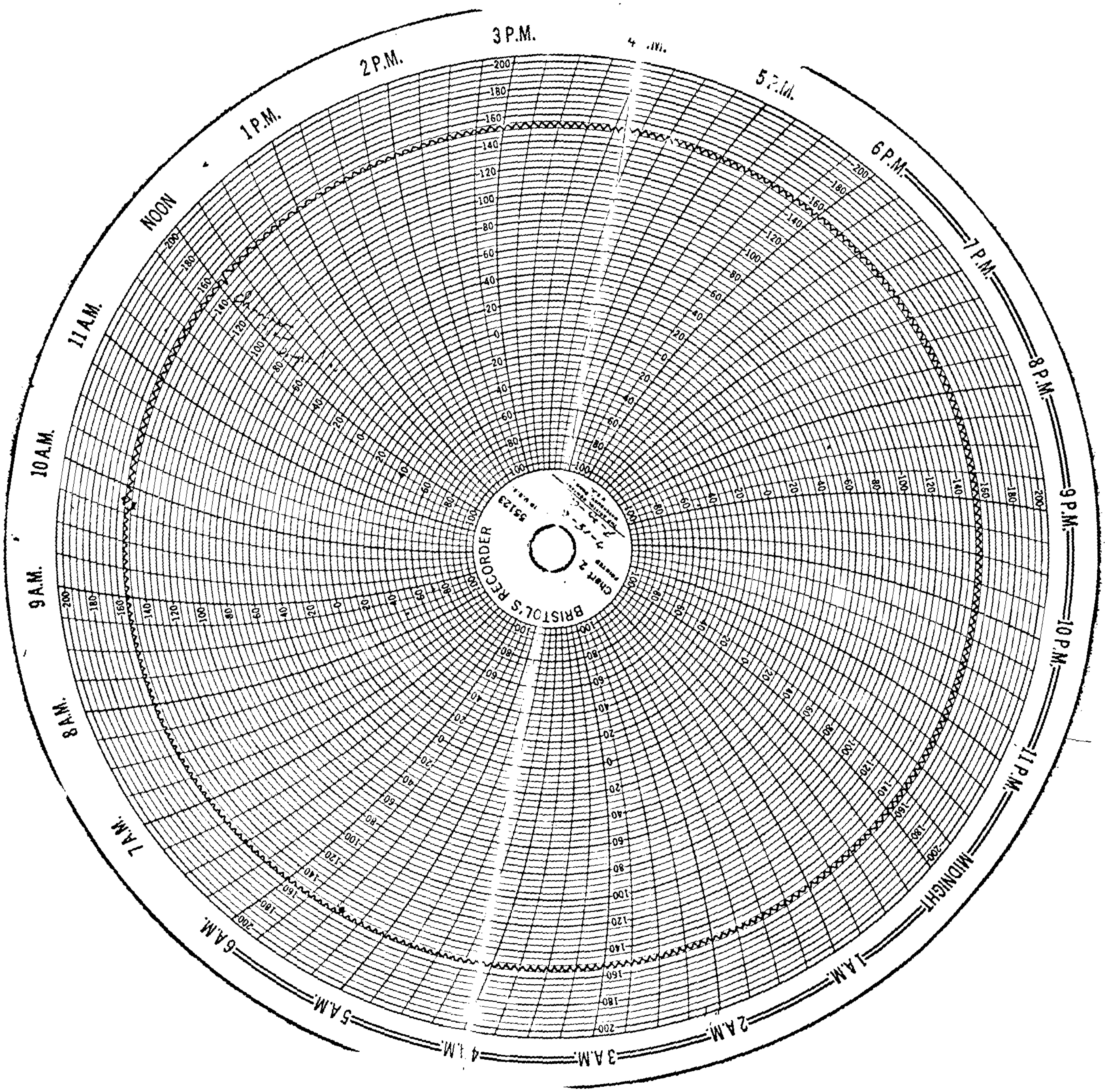
| | |
|---|---|
| 1 | High Temperature |
| 2 | Low Temperature |
| 3 | Temperature-Altitude |
| 4 | Vibration |

Table 2
Vibration Control and Recording Equipment

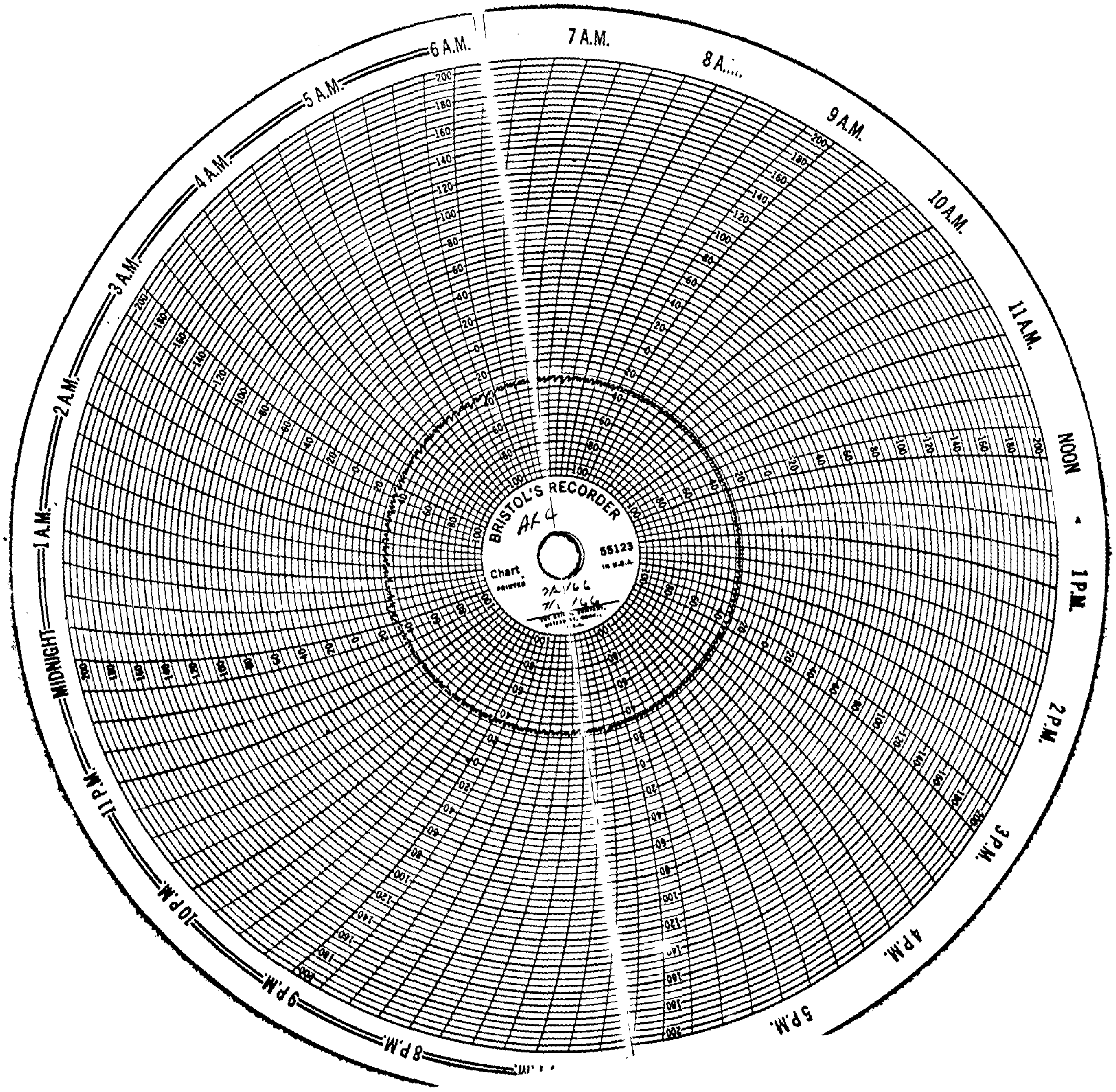
| Item Number | Equipment | Manufacturer | Model Number |
|---|---|---|---|
| 1 | Accelerometer | Endevco | 2213C |
| 2 | Amplifier | Endevco | 2614 |
| 3 | Power Supply | Endevco | 2621 |
| 4 | Analyzer-Tracking Filter | Spectral Dynamics | SD101A |
| 5 | Automatic Vibration Exciter Control | B & K | 1028 |
| 6 | Constant Output Level Adapter | Spectral Dynamics | SD-11 |
| 7 | Power Amplifier | Ling | T-97 |
| 8 | Galvanometer Amplifier | Honeywell | TG6A-500 |
| 9 | Recorder | Honeywell Visicorder | 1012 |
| 10 | Tape Recorder | Ampex | FR-1300 |

Table 3
Tape Recorder Playback

| Item Number | Equipment | Manufacturer | Model Number |
|---|---|---|---|
| 1 | Tape Recorder | Ampex | FR-1300 |
| 2 | Analyzer-Tracking Filter | Spectral Dynamics | SD101A |
| 3 | Galvanometer Amplifier | Honeywell | TG6A-500 |
| 4 | Recorder | Honeywell Visi-corder | 1012 |




Typical High Temperature Chart




Typical Low Temperature Chart

APPENDIX "A"

INDEX

APPENDIX "A"

TEMPERATURE ALTITUDE LOG SHEET

| Date | Time | Temperature (°F) | Altitude (ft) | Manometer Reading (in. of Hg) |
|---|---|---|---|---|
| 7-23-66 | 7:00 A.M. | 65 | Sea Level | 0 |
| 7-23-66 | 8:00 A.M. | 90 | Sea Level | 0 |
| 7-23-66 | 9:00 A.M. | 89 | 50,000 | 25.5 |
| 7-23-66 | 9:30 A.M. | 86 | 50,000 | 25.5 |
| 7-23-66 | 10:00 A.M. | 66 | 50,000 | 25.5 |
| 7-23-66 | 10:30 A.M. | 66 | 50,000 | 25.5 |
| 7-23-66 | 11:30 A.M. | 5 | 50,000 | 25.5 |
| 7-23-66 | 12:00 | 15 | 50,000 | 25.5 |
| 7-23-66 | 1:00 P.M. | -25 | 50,000 | 25.5 |
| 7-23-66 | 3:00 P.M. | -29 | 50,000 | 25.5 |
| 7-23-66 | 3:30 P.M. | -29 | 50,000 | 25.5 |
| 7-23-66 | 4:00 P.M. | -36 | 50,000 | 25.5 |
| 7-23-66 | 5:00 P.M. | -35 | 50,000 | 25.5 |
| 7-23-66 | 6:00 P.M. | 80 | Sea Level | 0 |
| 7-23-66 | 7:00 P.M. | 82 | Sea Level | 0 |
| 7-23-66 | 8:00 P.M. | 86 | Sea Level | 0 |

Legend: Barometric Pressure = 29.174 inches of mercury

°F = degrees fahrenheit

ft = feet

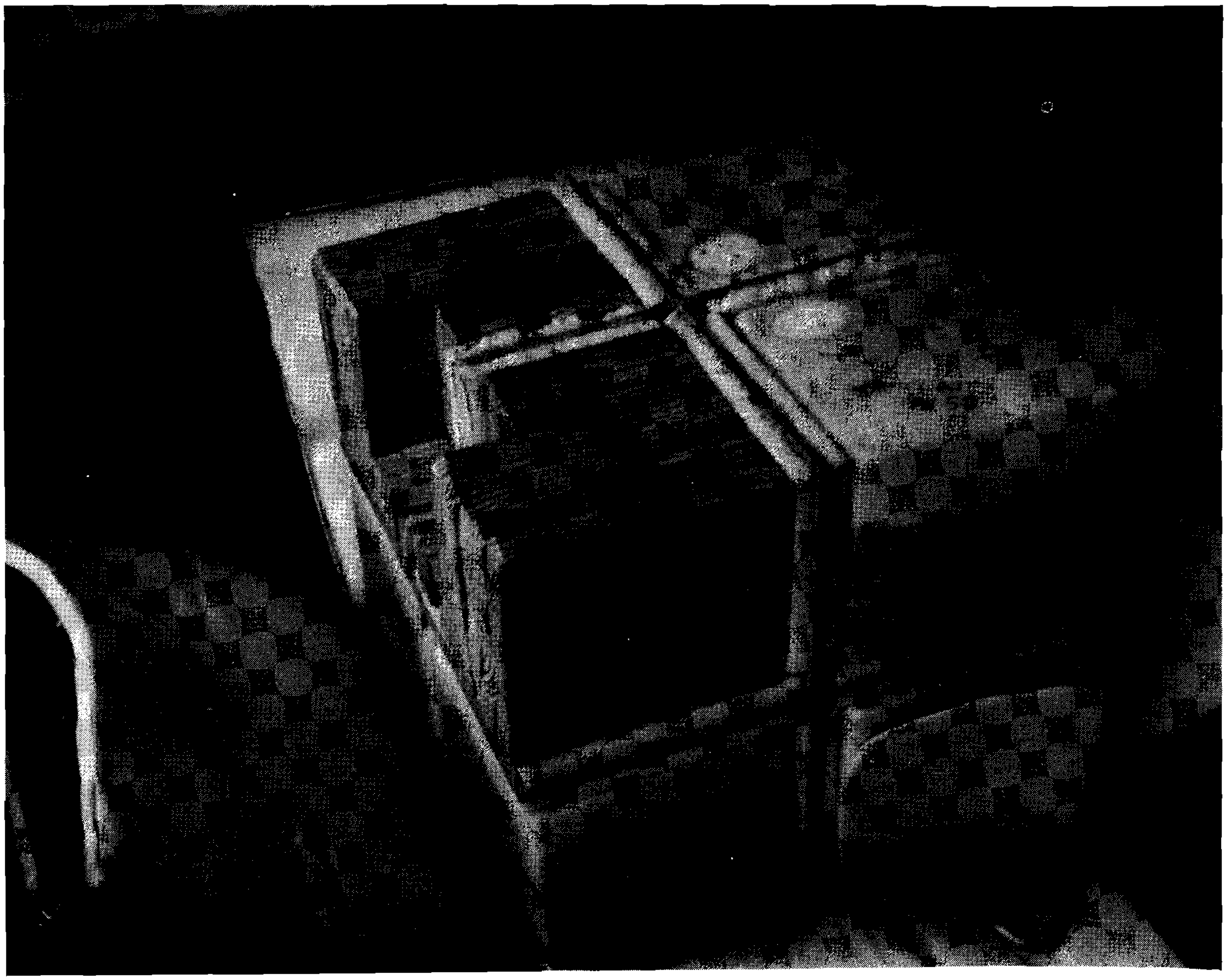
in. of Hg = inches of mercury

VIBRATION DATA SHEET

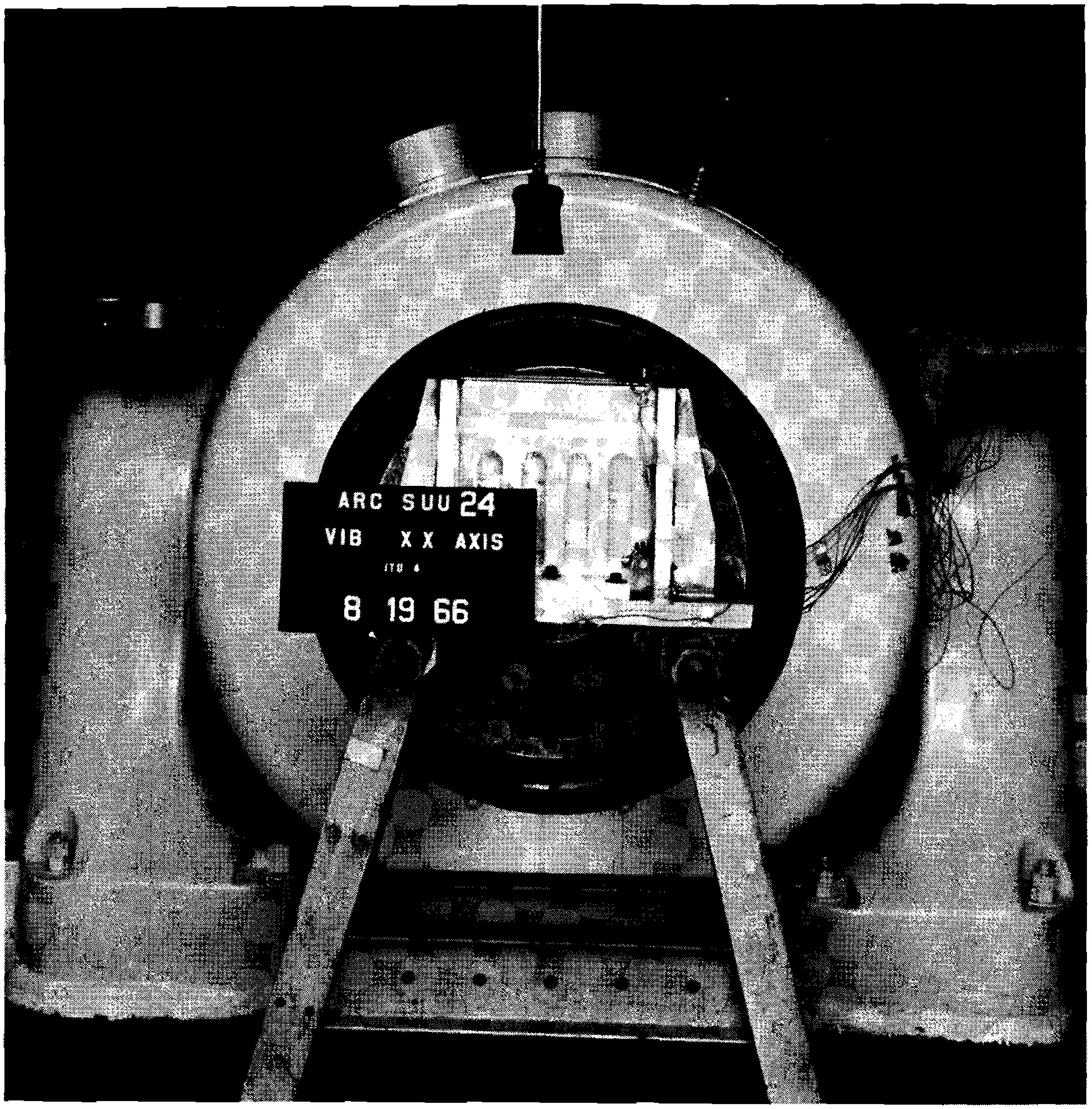
Resonant Frequencies

| Serial Number | X-X Axis (cps) | Y-Y Axis (cps) | Z-Z Axis (cps) |
|---|---|---|---|
| 1-TU-2 | 323 | 394 | 282 |
| | 499 | 457 | |
| 1-TU-3 | 255 | 287 | 124 |
| | 296 | | 286 |

**Legend:** cps = cycles per second



Temperature - Altitude Failure




Vibration X-X Axis

APPROVALS

Environmental Test Report
For
Atlantic Research Corporation
On
Incendiary Bombs

This test was conducted at the TRW-Roanoke Laboratories, Rocky Mount, Virginia, July 23rd through July 30th, 1966.

/s/ S. P. Funkhouser
S. P. Funkhouser
Test Engineer

/s/ Charles D. Waring
C. D. Waring
Operations Manager

/s/ R. E. Ruhfel /CDW
R. E. Ruhfel
Manager

APPENDIX III

Environmental Test Report RL 2098
for
Atlantic Research Corporation
On Incendiary Bombs

September 1966

TRW, Incorporated
Roanoke Laboratories
Rocky Mount, Virginia

TABLE OF CONTENTS

## LIST OF ILLUSTRATIONS



## LIST OF CHARTS



## LIST OF TABLES

ABSTRACT

This report covers the environmental tests as listed in Table I performed on Atlantic Research Corporation's Incendiary Bomb, part number SUU-24A. The results of these tests are recorded in the Test Results section of this report.

There was no visual evidence of failure on these units, following tests in the different environments; except for the loosening of the timer wheels during vibration.

A. SCOPE

This report presents the results of the environmental tests, as presented in Table I, that were performed on the Atlantic Research Corporation's Incendiary Bombs, part number SUU-24A, serial numbers 004, 005 and 006. These tests were conducted in accordance with Atlantic Research Corporation Procedure ETS-014-82-5819.

B. TEST REQUIREMENTS

The environmental test specification specified that the individual units be subjected to the following sequence of tests.

1. High Temperature - Each unit shall be subjected to an ambient temperature of 150 degrees fahrenheit for a period of 48 hours. At the conclusion of this period, the units shall be removed from the test chamber and inspected by Atlantic Research Corporation personnel.

2. Low Temperature - Each unit shall be placed in an ambient temperature of minus 30 degrees fahrenheit for a period of 48 hours. At the conclusion of this period, the unit shall be removed from the test chamber and inspected by Atlantic Research Corporation personnel.

3. Temperature Cycle - Each unit shall be placed in a test chamber and subjected to the following sequential environments.

| Sequence | Temperature (degrees fahrenheit) | Altitude (feet) | Time (hours) |
|---|---|---|---|
| 1 | Ambient | Sea level | - - |
| 2 | 85 | 50,000 | 0.5 |
| 3 | 65 | 50,000 | 1.0 |
| 4 | 10 | 50,000 | 1.0 |
| 5 | -20 | 50,000 | 2.0 |
| 6 | -30 | 50,000 | 1.0 |
| 7 | 85 | Sea level | 1.0 |

At the conclusion of this test, each unit shall be inspected by Atlantic Research Corporation personnel.

4. Humidity Cycle - Each unit shall be placed in a test chamber and subjected to 10 24-hour cycles of temperature-humidity in accordance with the procedure of Mil-STD-810A, method 507.1 except that the maximum temperature shall be limited to 150 degrees fahrenheit. At the conclusion of this test, each unit shall be inspected by Atlantic Research Corporation personnel.

5. Vibration - Each unit shall be subjected to the sinusoidal vibration test contained in Mil-STD-810A, method 514.1, utilizing the following conditions:

Class 1
Mount A
Curve B

At the conclusion of this test, each unit shall be inspected by Atlantic Research Corporation personnel.

6. Sand and Dust - Each unit shall be subjected to the sand and dust test of Mil-STD-810A, method 510.1; except the maximum temperature shall be limited to 150 degrees fahrenheit.

7. Salt Fog - Each unit shall be subject to the salt fog test of Mil-STD-810A, method 509.1.

## C. TEST PROCEDURE

The test specimens were subjected to the following sequence of tests.

1. High Temperature -

   a. The test specimens were placed in the test chamber at ambient temperature.
   b. Chamber temperature was increased to 150 degrees fahrenheit and stabilized.
   c. A 48 hour test cycle was conducted.
   d. The unit was inspected by Atlantic Research Corporation personnel.

2. Low Temperature -

   a. The test specimens were placed in the test chamber at ambient temperature.
   b. The chamber temperature was reduced to minus 30 degrees fahrenheit and stabilized.
   c. The stabilized temperature of minus 30 degrees fahrenheit was maintained for 24 hours.
   d. The chamber temperature was returned to ambient.
   e. The units were inspected by Atlantic Research Corporation personnel.

3. Temperature-Altitude -

   a. The test specimens were installed in a vacuum temperature chamber.
   b. Temperature and pressure were stabilized at ambient condition.
   c. Pressure was reduced to 50,000 feet, and temperature of 85 degrees fahrenheit was maintained for one half hour.

d. The temperature was reduced to 65 degrees fahrenheit while the 50,000 feet altitude was maintained. These conditions were maintained for one hour.
e. The temperature was reduced to 10 degrees fahrenheit and 50,000 feet altitude was maintained. These conditions were maintained for one hour.
f. The temperature was reduced to minus 20 degrees fahrenheit, and altitude was raised to 50,000 feet. These conditions were maintained for two hours.
g. The temperature was reduced to minus 30 degrees fahrenheit, and altitude was maintained at 50,000 feet. These conditions were maintained for one hour.
h. The temperature was increased to 85 degrees fahrenheit while the pressure was returned to sea level.
i. The test specimens were removed from the chamber, and inspected by Atlantic Research Corporation personnel.

4. Vibration -

a. A sinusoidal survey was conducted from 5-500-5 cycles per second, recording th input and response accelerometers on the visicorders and magnetic tape. (See Figure 2 and Table 2)
b. The response accelerometers were individually played back through the tracking filter and recorded on the visicorder. (See Figure 3 and Table 3)
c. From the reproduced data, the resonant points were established.
d. Each of the resonant points established was subjected to 30 minutes of vibration.
e. Additional cycles were performed between 5-500-5 cycles per second for 15 minutes to provide three hours total vibration.
f. Steps a. through e. were repeated for each of the remaining two axis.
g. At the conclusion of vibration testing, each unit was inspected by Atlantic Research Corporation personnel.

5. Sand and Dust -

a. The specimens were placed in the sand and dust chamber.
b. The density of sand and dust was raised to the range of 0.1 to 0.25 grams per cubic foot.
c. The internal chamber temperature was stabilized at 77 degrees fahrenheit and maintained for two hours with air velocity through the test chamber at 100 to 500 feet per minute.
d. At the end of the two hour period, the temperature was increased to 140 degrees and maintained for two hours.
e. The units were removed from the test chamber.

6. Salt Fog - The specimens were supported in the salt fog chamber on nylon cord, and subjected to 48 hours exposure.

## D. TEST HISTORY

The following tests were conducted during the days indicated below:

| | |
|---|---|
| High Temperature | 8-4-66 to 8-6-66 |
| Low Temperature | 8-6-66 to 8-8-66 |
| Temperature-Altitude | 8-8-66 to 8-9-66 |
| Humidity | 8-9-66 to 8-19-66 |
| Vibration | 8-19-66 to 8-22-66 |
| Sand and Dust | 8-23-66 |
| Salt Fog | 8-23-66 to 8-25-66 |

## E. TEST RESULTS

The environmental tests were completed without any evidence of physical or mechanical failure, with the exception of the loosening of the timer wheel during vibration tests. The set screw in the wheel which is used to set the timer spring came loose during vibration allowing the wheel to spin on its shaft. This condition did not affect the timer mechanism.

Data sheets and photographs of the various tests are found in Appendix "A" of this report.

TABLE I

ENVIRONMENTAL TESTS

| | |
|---|---|
| 1 | High Temperature |
| 2 | Low Temperature |
| 3 | Temperature-Altitude |
| 4 | Temperature-Humidity |
| 5 | Vibration |
| 6 | Sand and Dust |
| 7 | Salt Fog |

12621

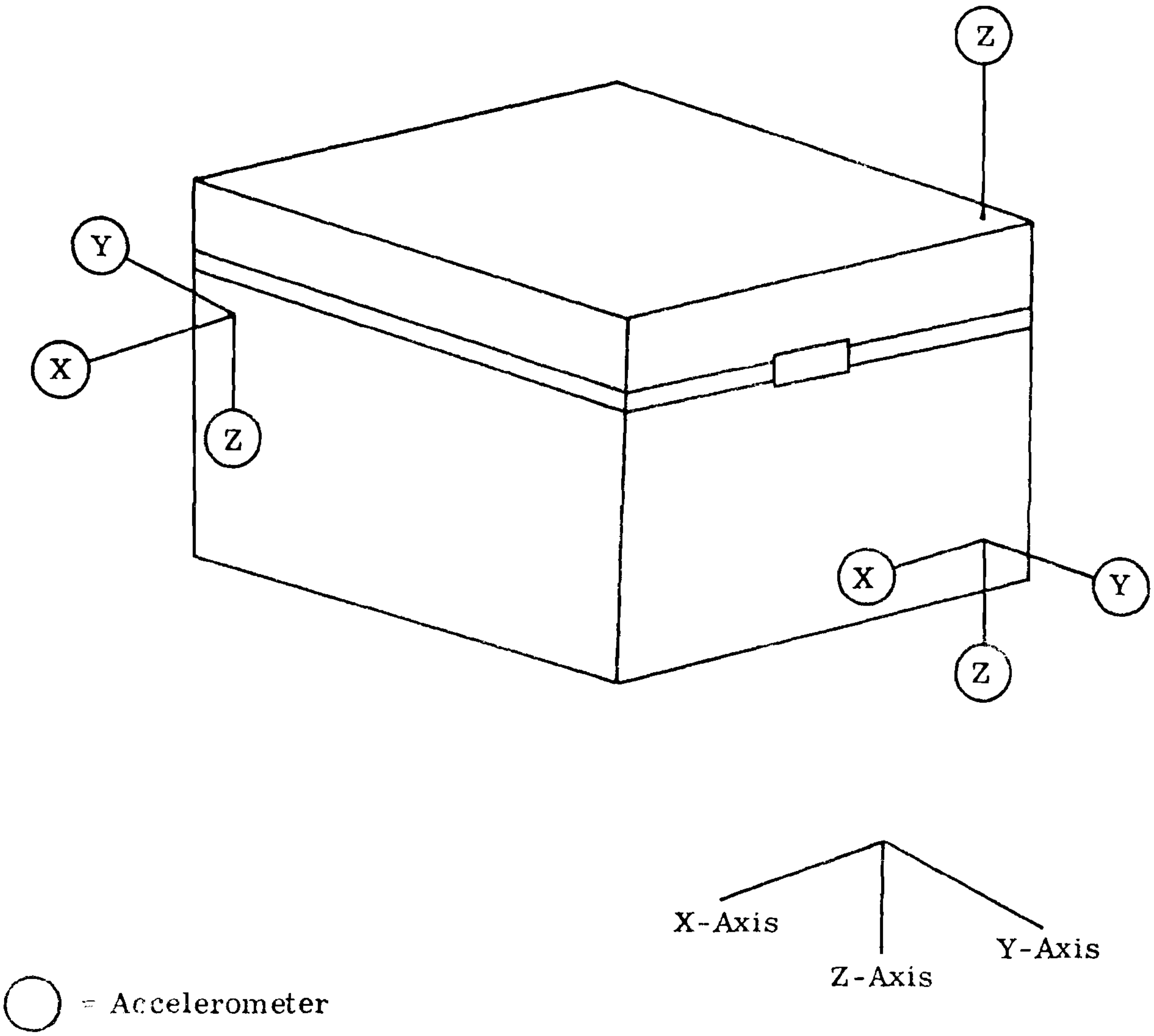
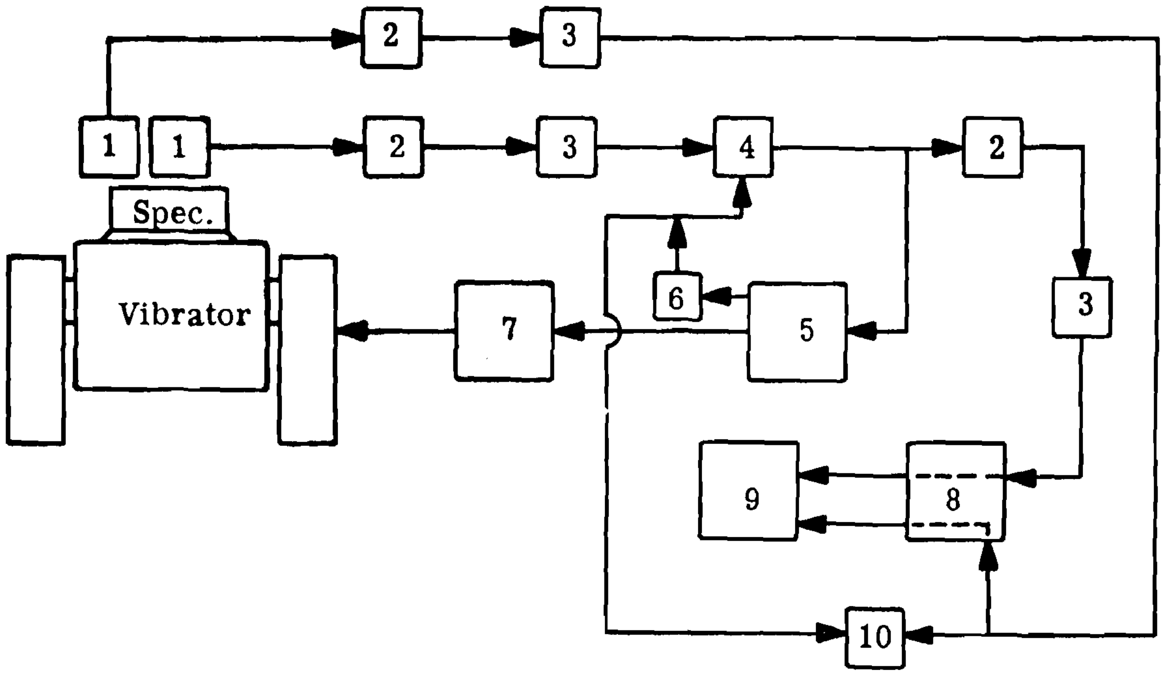



Figure 1. Axis of Vibration and Accelerometer Locations.

12619



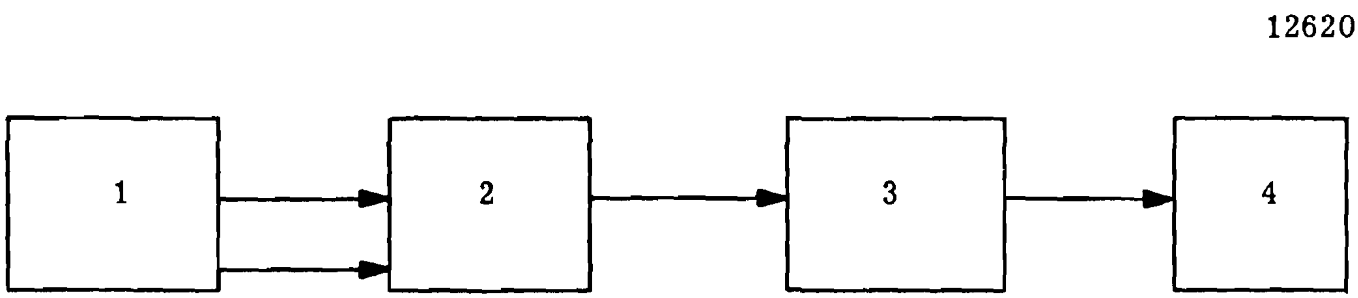

See Table 2 for Equipment List

Figure 2. Vibration Control and Recording Channels.

Table 2

Vibration Control and Recording Equipment

| Item Number | Equipment | Manufacturer | Model Number |
|---|---|---|---|
| 1 | Accelerometer | Endevco | 2213C |
| 2 | Amplifier | Endevco | 2614 |
| 3 | Power Supply | Endevco | 2621 |
| 4 | Analyzer-Tracking Filter | Spectral Dynamics | SD101A |
| 5 | Automatic Vibration Exciter Control | B & K | 1028 |
| 6 | Constant Output Level Adapter | Spectral Dynamics | SD-11 |
| 7 | Power Amplifier | Ling | T-97 |
| 8 | Galvanometer Amplifier | Honeywell | TG6A-500 |
| 9 | Recorder | Honeywell Visicorder | 1012 |
| 10 | Tape Recorder | Ampex | FR-1300 |



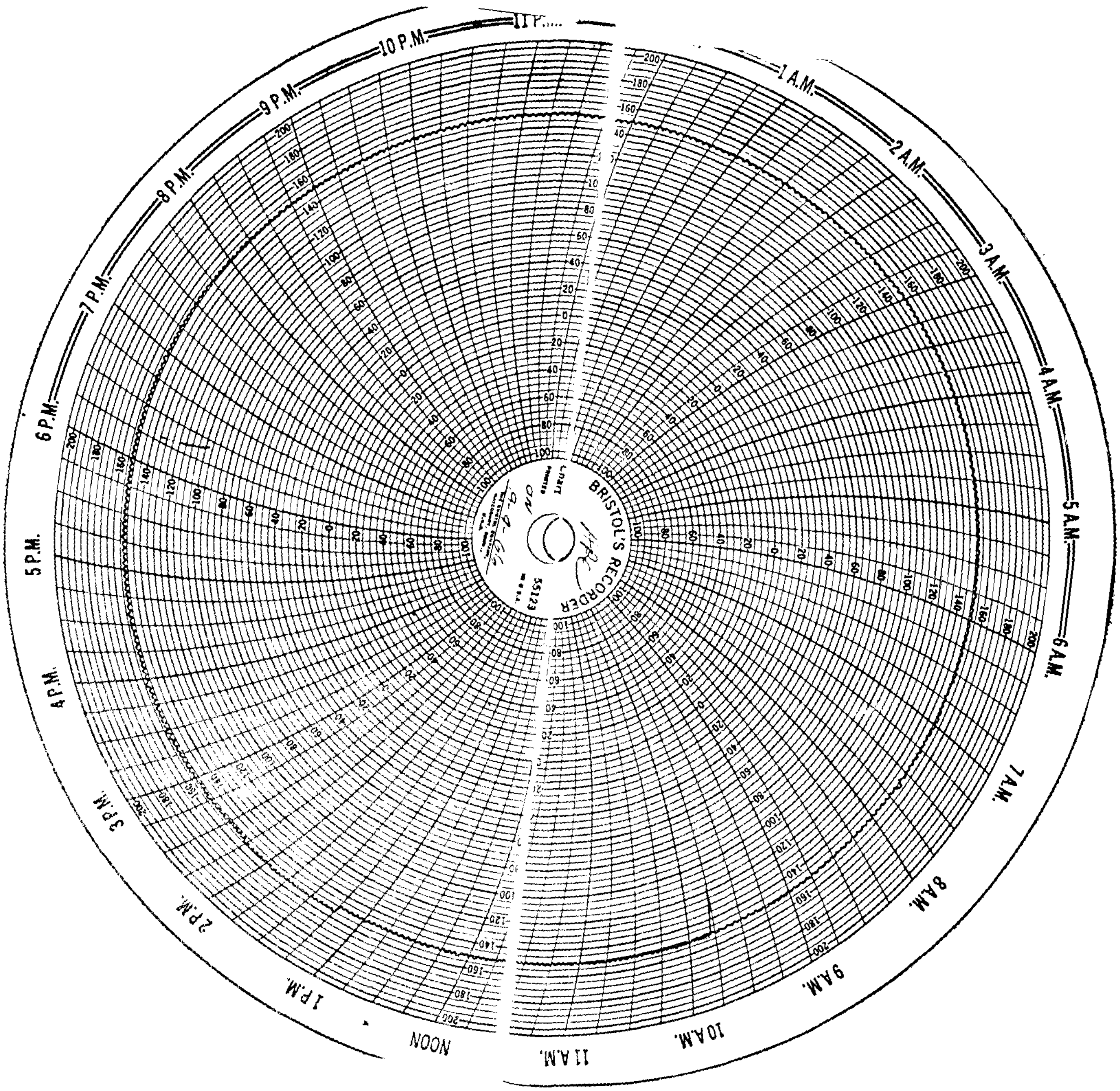

See Table 3 for Equipment List

Figure 3. Tape Recorder Playback.

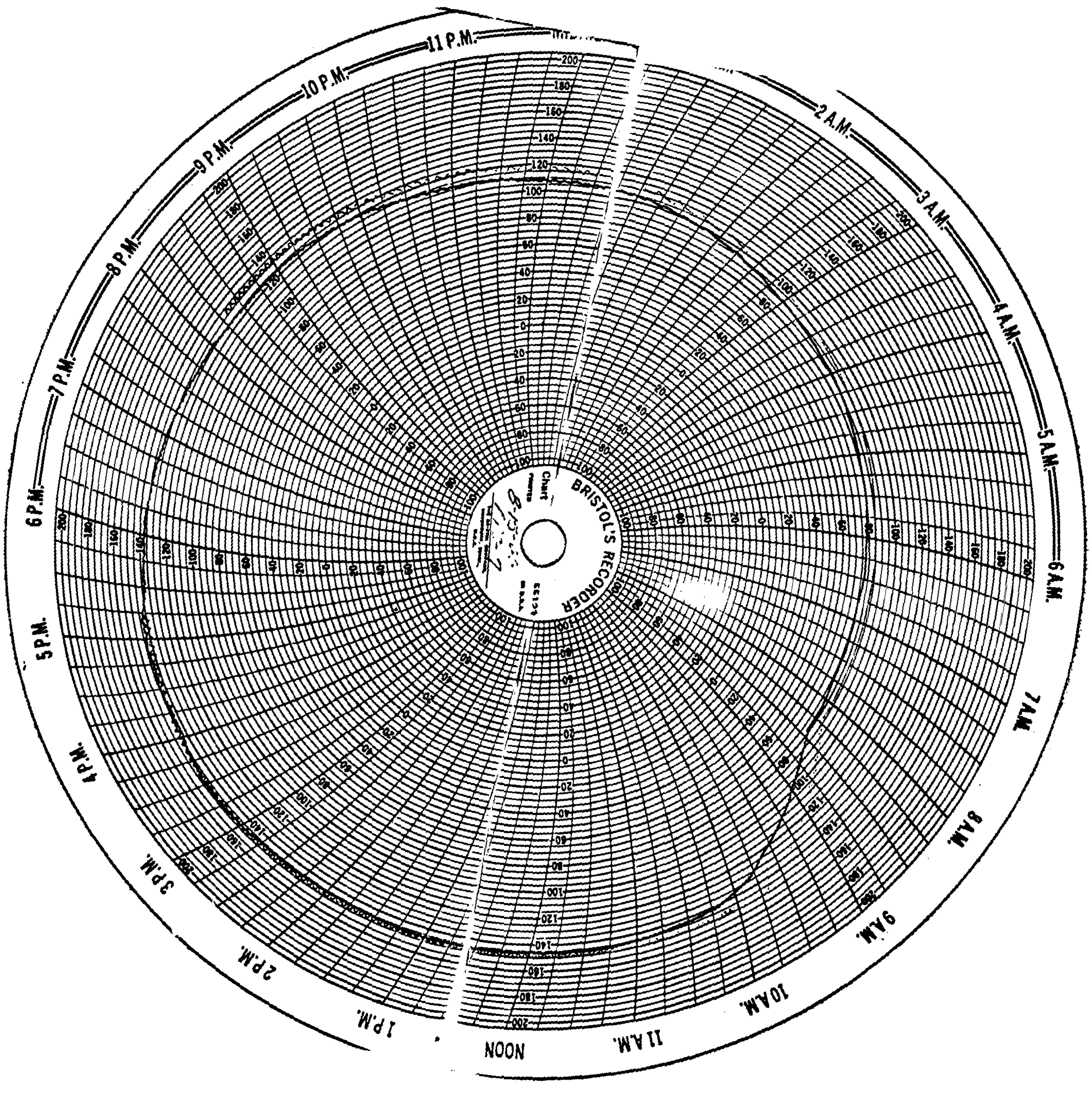
Table 3

Tape Recorder Playback

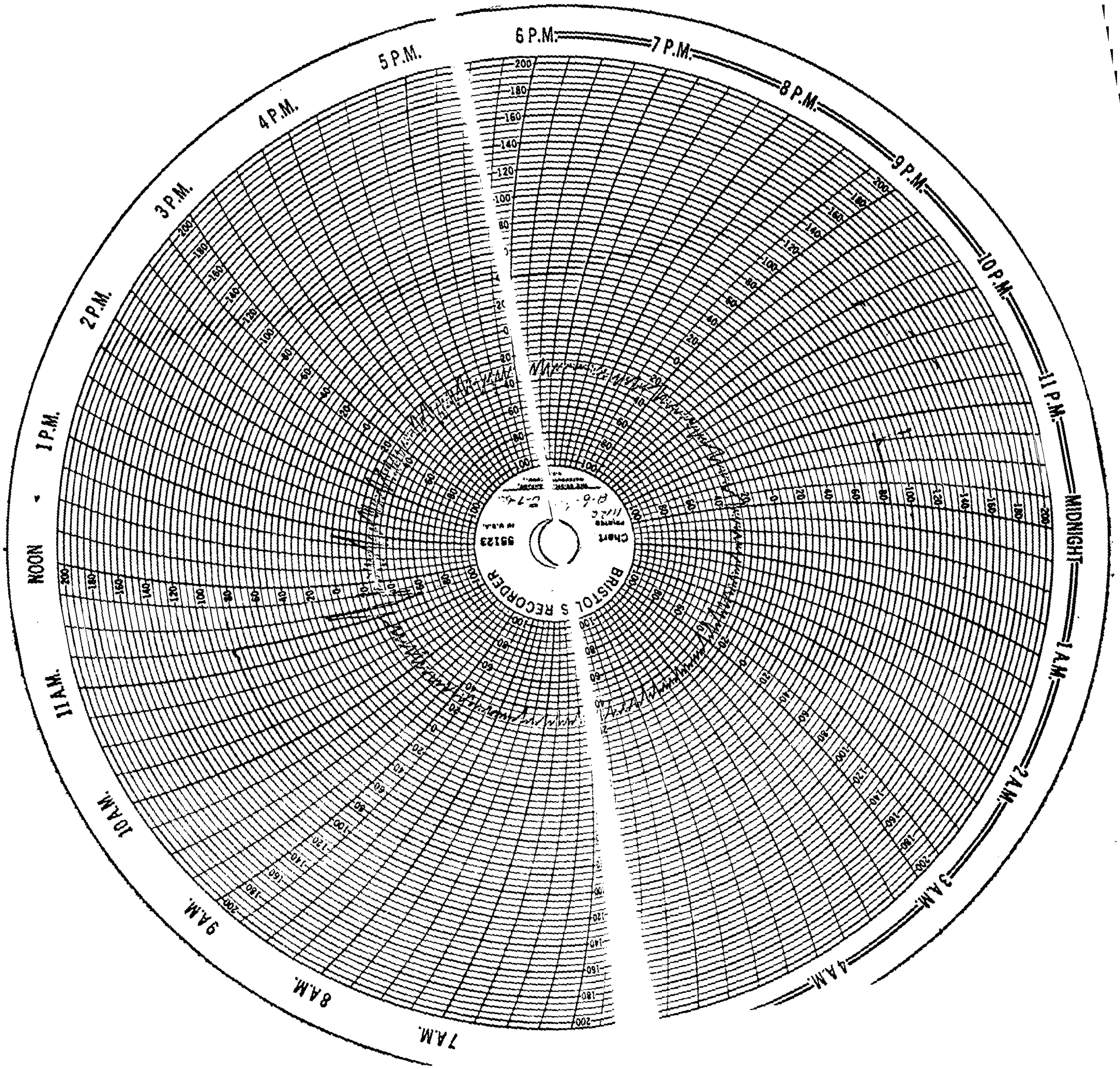
| Item Number | Equipment | Manufacturer | Model Number |
|---|---|---|---|
| 1 | Tape Recorder | Ampex | FR-1300 |
| 2 | Analyzer-Tracking Filter | Spectral Dynamics | SD101A |
| 3 | Galvanometer Amplifier | Honeywell | TG6A-500 |
| 4 | Recorder | Honeywell Visi-corder | 1012 |




Typical High Temperature Chart




Typical Temperature-Humidity Chart




Typical Low Temperature Chart

APPENDIX "A"

# INDEX

## APPENDIX "A"

TEMPERATURE ALTITUDE LOG SHEET

| Date | Time | Temperature (degrees fahrenheit) | Altitude (feet) | Vacuum (inches of mercury) |
|---|---|---|---|---|
| 8-8-66 | 5:00 P.M. | 85 | sea level | 0 |
| 8-8-66 | 6:00 P.M. | 85 | sea level | 0 |
| 8-8-66 | 6:05 P.M. | 85 | 50,000 | 25.2 |
| 8-8-66 | 6:40 P.M. | 85 | 50,000 | 25.2 |
| 8-8-66 | 7:05 P.M. | 65 | 50,000 | 25.2 |
| 8-8-66 | 8:10 P.M. | 65 | 50,000 | 25.2 |
| 8-8-66 | 8:30 P.M. | 10 | 50,000 | 25.2 |
| 8-8-66 | 9:30 P.M. | 10 | 50,000 | 25.2 |
| 8-8-66 | 10:30 P.M. | -20 | 50,000 | 25.2 |
| 8-9-66 | 12:30 A.M. | -20 | 50,000 | 25.2 |
| 8-9-66 | 1:30 A.M. | -30 | 50,000 | 25.2 |
| 8-9-66 | 2:30 A.M. | -30 | 50,000 | 25.2 |
| 8-9-66 | 3:30 A.M. | 85 | sea level | 0 |
| 8-9-66 | 4:30 A.M. | 85 | sea level | 0 |

NOTE: Barometric Pressure = 29.6 inches of mercury

VIBRATION DATA SHEET

Resonant Frequencies

| Serial Number | X-X Axis (cycles per second) | X-Y Axis (cycles per second) | Z-Z Axis (cycles per second) |
|---|---|---|---|
| 1-TU-4 | 240 | 190 | 448 |
| | 369 | 312 | |
| 1-TU-5 | 220 | 96 | 342 |
| | | 219 | |
| 1-TU-6 | 291 | 232 | 431 |

## SALT SPRAY DATA SHEET

| | | |
|---|---|---|
| Method of supporting sample in chamber | - | nylon cord |
| Type of salt used | - | United States Pharmacopoeia Code 2226 |
| Salt Concentration | - | Weight 5 percent |

## CHAMBER CONDITIONS

| Exposure Time (hours) | Chamber Temp. (°F) Wet Bulb | Dry Bulb | Vol. Spray Collected Mil/hr/80 cm$^2$ Near (cc) | Far (cc) | Specific Gravity Spray Sample Temp. (°F) | Sp. Gr. | pH Spray Sample |
|---|---|---|---|---|---|---|---|
| 0 | 96 | 96 | 0 | 0 | 95 | 1.03 | 6.9 |
| 23 | 96 | 96 | 6 | 9 | 95 | 1.03 | 6.9 |
| 48 | 95 | 95 | 10 | 16 | 95 | 1.03 | 6.9 |

LEGEND:

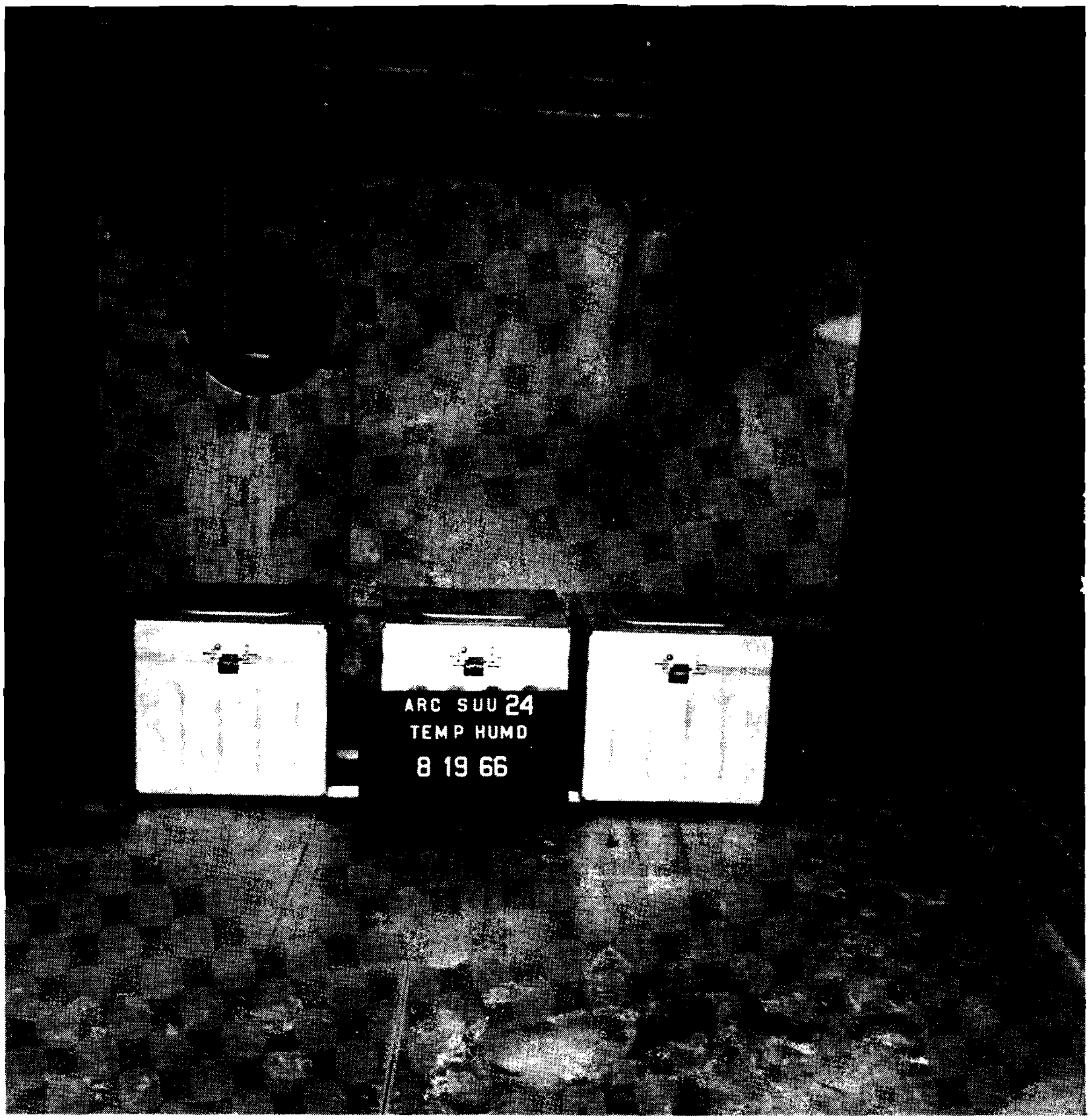
| | | |
|---|---|---|
| °F | - | degrees fahrenheit |
| Temp. | - | temperature |
| Vol. | - | volume |
| Mil/hr/80 cm$^2$ | - | milliliters per hour per 80 centimeters squared |
| cc | - | cubic centimeters |
| Sp. Gr. | - | specific gravity |
| pH | - | percentage hydrogen ion concentration |

## SAND AND DUST DATA SHEET

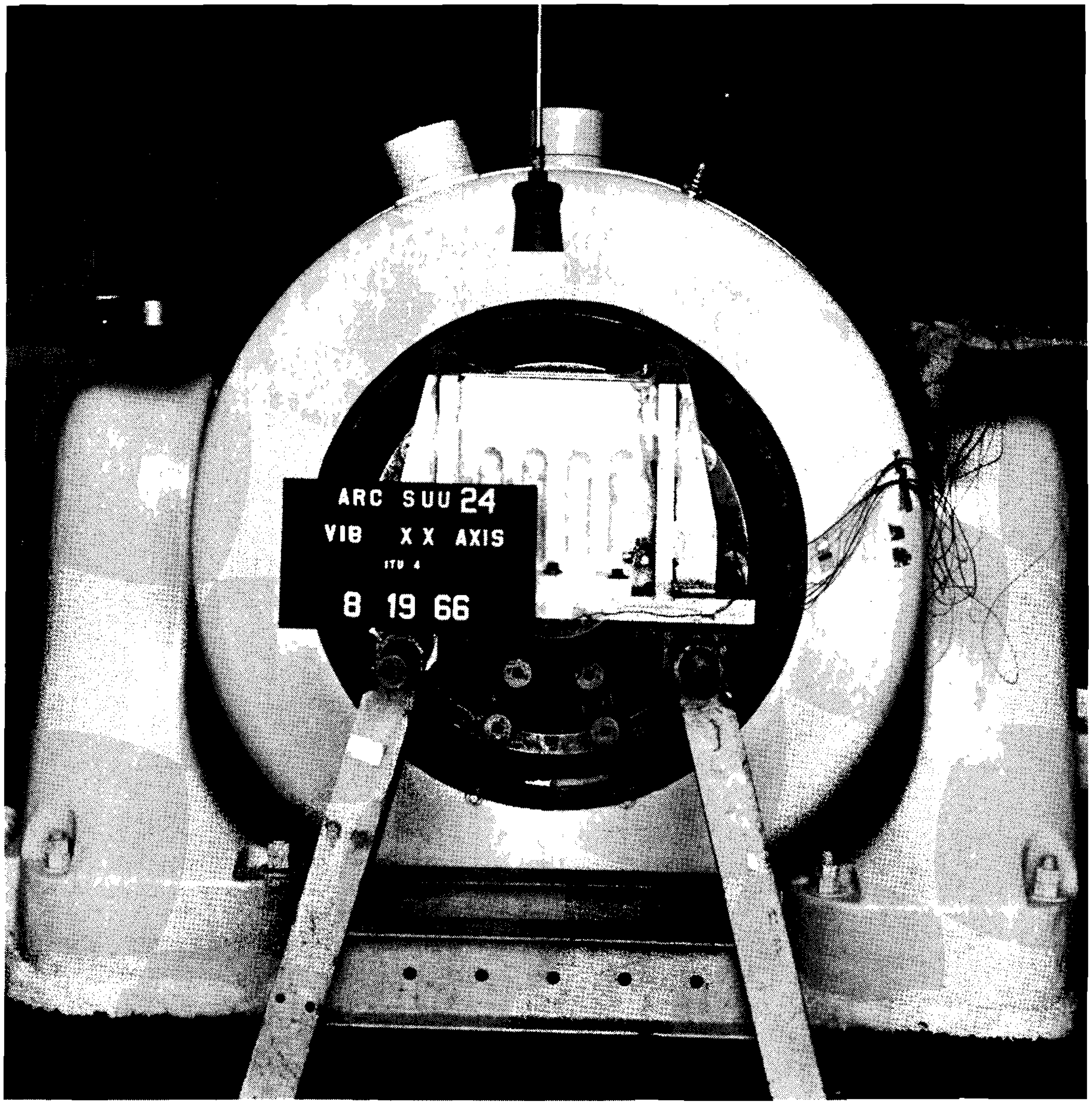
Chemical Analysis:

| Substance | Percent by Weight |
|---|---|
| $SiO_2$ | 97 to 99 |
| $Fe_2O_3$ | 0 to 2 |
| $Al_2O_3$ | 0 to 2 |
| $TiO_2$ | 0 to 2 |
| MgO | 0 to 1 |
| Inorganic losses | 0 to 1 |

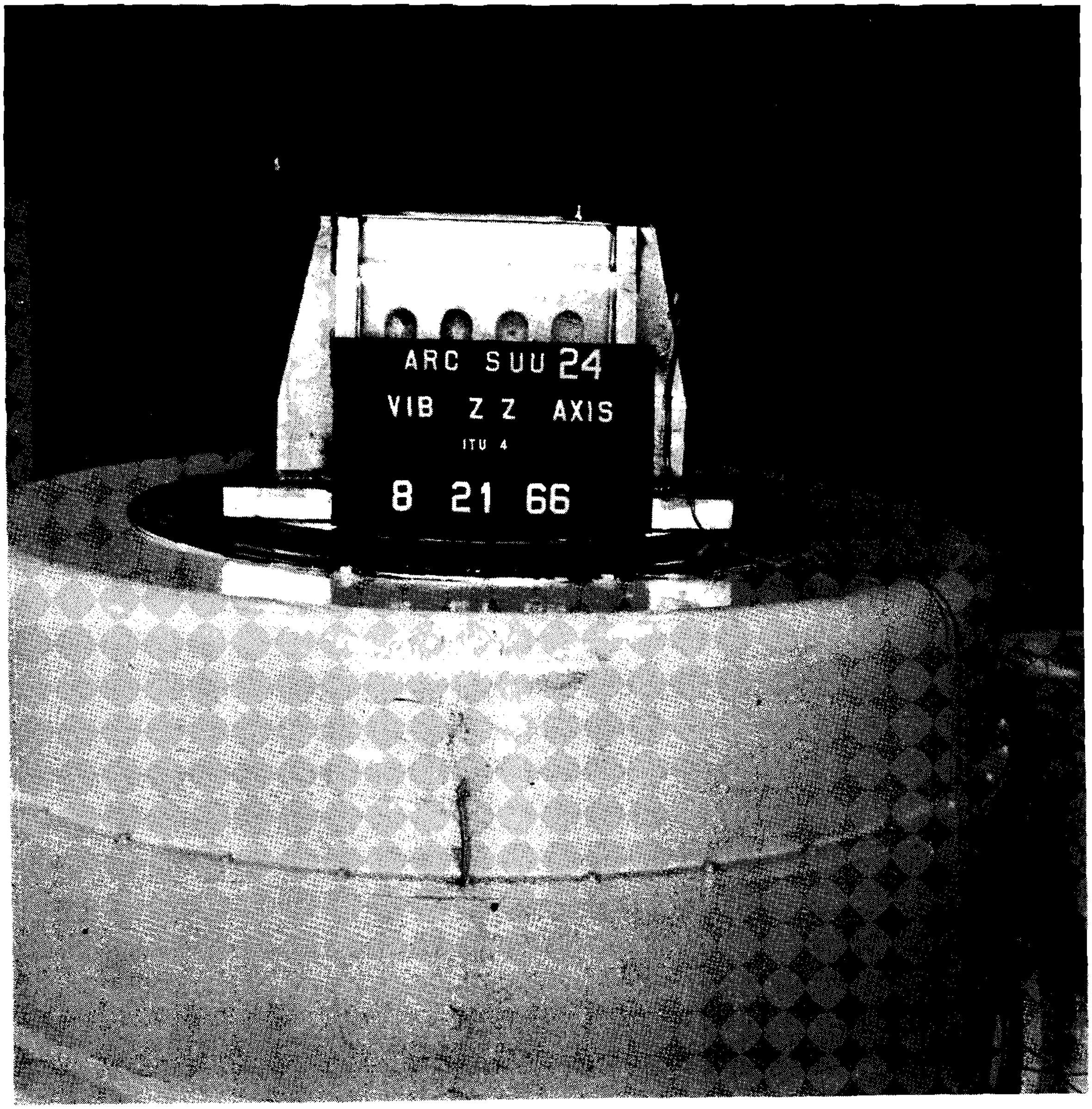
| Time (hours) | Temperature (degrees fahrenheit) | Dust Density Grams Per Cubic Feet |
|---|---|---|
| 0 | 77 | 0.1 to 0.25 |
| 2.0 | 77 | 0.1 to 0.25 |
| 2.5 | 150 | 0.1 to 0.25 |
| 4.5 | 150 | 0.1 to 0.25 |




Temperature-Humidity Setup




Vibration - X-X Axis




Vibration - Z-Z Axis

APPROVALS

REPORT OF TESTING

ON

INCENDIARY BOMBS

FOR

ATLANTIC RESEARCH CORPORATION

This test was conducted at TRW-Roanoke Laboratories, Rocky Mount, Virginia, 8-4-66 through 8-25-66.

| ORIGINATOR: | APPROVALS: |
|---|---|
| /s/ S. P. Funkhouser | /s/ Charles D. Waring |
| S. P. Funkhouser<br>Project Engineer | C. D. Waring<br>Operations Manager |
| | /s/ R. E. Ruhfel |
| | R. E. Ruhfel<br>Manager |

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| DPLB-1 | 4 |
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| Det 1, 2705 Ammo Wg USN EOD Facility | 1 |
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| Code 753 (Tech Lib) | 1 |
| Code 40705 | 1 |
| Code 403 | 1 |
| Code 4071 | 1 |
| Code 4036 | 1 |
| Code 4543 | 1 |
| USN Applied Sci Lab Tech Lib, Bld 1 Code 222 | 1 |
| AFSC STLO | |
| SCTL-5 | 1 |
| SCTL-2 | 1 |
| SCTL-4 | 1 |
| SCTL-16 | 1 |
| SCTL-19 | 1 |
| SCTL-21 | 1 |
| SCTL-24 | 1 |
| SCTL-1 | 1 |
| SCTL-18 | 1 |
| SCTL-10 | 1 |
| SCTL-12 | 1 |
| SCTL-13 | 1 |
| SCTL-6 | 1 |
| SCTL-15 | 1 |
| SCTL-3 | 1 |
| SCTL-7 | 1 |
| AMSEL-RD-LNA | 1 |
| SCTL-11 | 1 |

| | |
|---|---|
| DDC | 20 |
| PGBPS-12 | 4 |
| PGLW | 1 |
| PGLPP | 1 |
| PGVED-1 | 1 |
| PGOWB | 1 |
| SAWC (DO) | 1 |
| TAWC | |
| DTCL | 1 |
| OA | 1 |
| DRQ | 1 |
| OOY-G | 8 |
| ATG | 1 |
| ATC (CCLO) | 1 |
| ATCB | 1 |
| ATCC | 5 |
| ATCD | 1 |
| Atlantic Research Corp | 2 |



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UNCLASSIFIED

Security Classification

# DOCUMENT CONTROL DATA - R&D

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13. ABSTRACT


A flame bomb for high-altitude aircraft delivery from the SUU-24/A dispenser was designed and developed to minimize cratering effects and to provide maximum effective dispersion of the flame fuel. The flame fuel (napalm-B type) is contained in eight frangible plastic cases, approximately 1 gallon each, which are packaged in the standard CBU-27 canister. After the canister is dropped from the dispenser it is opened at a predetermined altitude and the bombs are deployed over the target. On impact, the bomb cases shatter, dispersing the flame fuel which is ignited by breakage of a vial of triethylaluminum. Safety tests showed that inadvertent fracture of an igniter vial within a filled bomb or accidental dropping of a loaded CBU-27 canister would not result in ignition. Bombs subjected to environmental testing in canisters functioned properly when impacting at terminal velocity after a 700-foot drop. Additional drops of single bombs at 700 feet and loaded canisters at 1000 feet were all successful. Eighteen units were delivered to the Air Force for flight tests.

| 14 KEY WORDS | LINK A | | LINK B | | LINK C | |
|---|---|---|---|---|---|---|
| | ROLE | WT | ROLE | WT | ROLE | WT |
| Flame bombs | | | | | | |
| Delrin (acetal resin plastic) | | | | | | |
| Igniters | | | | | | |
| Triethylaluminum | | | | | | |
| SUU-24/A (munition dispenser) | | | | | | |
| CBU-27 (munition canister) | | | | | | |
| Flame fuels | | | | | | |
| Napalm | | | | | | |

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