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AFAPL-TR-69-66

# DEVELOPMENT OF FULL SCALE PYROTECHNIC GENERATED GAS DISCHARGE FIRE EXTINGUISHING :SYSTEM

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WALTER KIDDE & COMPANY, INC.

TECHNICAL REPORT AFAPL-TR-69-66

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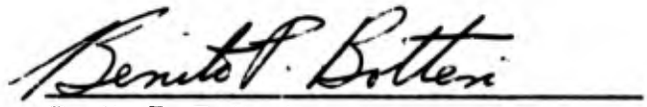
## FOREWORD

This report covers the work performed under Project 3048, "Fuels, Lubrication and Hazards" Task 304807, "Aerospace Vehicle Hazard Protection" by Walter Kidde & Company, Inc., 675 Main Street, Belleville, New Jersey under U.S. Air Force Contract AF-33615-68-C-1121. The program was monitored by R.E. Cretcher, Aero Propulsion Laboratory (APFH). The assistance given by A. Munn, Project Leader, and J. DeRosa, Test Engineer, in the conduct of this program is appreciated.

Kidde is especially grateful for the considerable cooperation extended to this program by E.I. duPont de Nemours & Company. The assistance given by National Aviation Facilities Experimental Center (NAFEC) personnel, C. Middlesworth and J. Gassman in the conduction of the fire test program is also appreciated.

This report was submitted by the authors April 1969.

This technical report has been reviewed and is approved.



Benito P. Botteri
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## ABSTRACT

Advanced aircraft operating in supersonic and hypersonic flight regimes impose many environmental problems on aircraft subsystems. Fire extinguishing equipment will be required to operate efficiently over a -65° F to 500° F temperature range. To meet this requirement, a full scale Pyrotechnic Fire Extinguishing System was designed, developed and fire tested under simulated flight conditions. This Pyrotechnic Extinguishing System (wherein pyrotechnic pressurization replaces nitrogen as an energy source) will function effectively under extreme environmental conditions and its performance on a weight effectiveness basis is superior to that of the standard nitrogen pressurized units.



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# SECTION I

# INTRODUCTION

## 1. SCOPE

Extinguishment and control of aircraft in-flight engine fires is currently accomplished by rapid distribution of a suitable fire extinguishing agent in sufficient quantity and time duration for the physical and chemical fire environmental conditions involved. Discharge of current systems is accomplished by high pressure nitrogen expulsion over a temperature range from -65° F to +160° F. As aircraft developments progress to flight capabilities in the supersonic and hypersonic regimes, the capability of the various aircraft sub-systems must be extended to allow satisfactory operation in the broader and higher temperature environments encountered. Recently a subscale fire extinguishing system using a pyrotechnic charge as the means for generating the agent expulsion gas was developed for conventional aircraft use. The potential application of this system to high temperature (to 500° F) operational environments has been explored and proven to be feasible on an experimental basis.

This report presents a summary of the results of a Pyrotechnic Fire Extinguishing System Investigation conducted under U.S. Air Force Contract AF-33615-68-C-1121. Under this contract engineering efforts have been expended to solve the problems involved in developing a full scale prototype pyrotechnic generated gas discharge fire extinguishing system capable of reliable operation over a -65° F to 500° F temperature range.

As a result of these efforts, a full scale self-pressurizing fire extinguishing system was designed and developed to be effective throughout the required operating temperature range. The full scale prototype system was then fire tested under simulated flight conditions and its performance was demonstrated over the required -65° F to 500° F temperature range. The fire conditions were simulated in a turbine engine nacelle mock-up at the Federal Aviation Agency, National Aviation Facilities Experimental Center (NAFEC), Atlantic City, New Jersey.

## 2. PURPOSE

The technical effort contained herein was directed toward the development of the pyrotechnic generated gas discharge fire extinguishing technique into a full scale prototype system. System design parameters were established so as to allow application of the system to high performance aircraft operating at the environmental extremes of -65° F to 500° F. An additional objective was the attainment of fire extinguishment effectiveness, on a system weight basis, which will meet or exceed that of the conventional HRD nitrogen pressurized systems.

## 3. RELATED EXPERIENCE

In-house research and development programs supplemented by Air Force funding during the last 15 years have resulted in advanced fire protection designs which are operable over a -65°F to 160°F temperature range utilizing $CF_2Br_2$ (Dibromodifluromothane) or $CF_3Br$ (monobromotrifluromethane) as extinguishing agents. These technologically advanced system configurations serve as a basis for the future development of equipment capable of high temperature performance.

In an effort to extend the operating temperature range and performance of the standard fire protection equipment, numerous feasibility programs concerned with the investigation of high temperature design paramets and the development of advanced fire exting ishing designs have been conducted. The culmination of these feasibility investigations has been the adoption of the pyrotechnic fire extinguishing concept as the most promising means of meeting the high temperature requirements imposed by the environmental extremes associated with advanced aircraft.

Some of the more recent programs in which Kidde has been involved, include the design and testing of a Pyrotechnic Extinguishing Unit for the Ling-Temco-Vought XC-142 aircraft, participation in the National Aviation Facilities Experimental Center (NAFEC) fire test program conducted at the U.S. Naval Air Turbine Test Station (NATTS), Trenton, N.J. and the development of a subscale pyrotechnic extinguishing unit capable of operation over a -65°F to 500°F temperature range under Air Force contract AF-33(615) 3648. The latter effort is presented in an Air Force Aero Propulsion Laboratory Technical Report (AFAPL-TR-68-47), "Investigation of Pryrotechnic Generated Gas Discharge Fire Extinguishing System," describing development of the subscale prototype system upon which this effort is based.

The test program at NATTS consisted of comparative tests of full scale nitrogen pressurized and pyrotechnically pressurized extinguishers. A direct comparison of one agent with another was difficult due to the instability exhibited by the standard fire during the course of the program. However, the test data sufficed to show that the pyrotechnic unit was more effective than the standard unit. This was demonstrated when comparing pound for poind of agent and pound for pound of container assembly.

In the pyrotechnic extinguishing program conducted for AFAPL, a subscale unit successfully extinguished nacelle fires at NAFEC while conditioned over a -65°F to 500°F temperature range. The performance of the subscale pyrotechnic system at room temperature was reasonable compared to the standard nitrogen system while the latter is not adaptable to operation at elevated temperatures.

The in-house work in pyrotechnic devices is not limited to the field of fire protection equipment. The same pyrotechnic gas generation technique has already been successfully employed to expel other liquefied agents, such as carbon dioxide, for the inflation of flotation and other inflatable devices. This experience contributed significantly to the conduct of this pyrotechnic extinguishing program.

## SECTION II

## TECHNICAL DISCUSSION

### 1. GENERAL

Advanced aircraft operating in the supersonic and hypersonic flight regimes require sophisticated subsystems which reflect high reliability, maintainability and minimal weight. In the field of fire extinguishing equipment, it will be necessary to provide more efficient extinguishing agents, improved pressure vessel designs and extinguishers capable of operating over a broader and higher temperature flight environment. In an effort to provide a system with which to achieve these goals, this program was undertaken.

The preliminary phase of this program was concerned with a general investigation of the anticipated problems areas and an analysis of the design modifications needed to scale up a previously developed subscale pyrotechnic extinguishing system. The second phase involved evaluation of various geometric designs of the solid propellant grain used for pressurization and the selection of a container (spherical or cylindrical) most suitable for application in the full scale system. The final phase consisted of a fire test program conducted at NAFEC to evaluate and modify the full scale system.

### 2. DESIGN

The basic design philosophy exhibited by the subscale pyrotechnic unit was such, that the full scale prototype unit could be scaled up to meet flight unit specifications with a minimum of modification. The primary difference between the two designs is the mounting of the propellant chamber. The chamber is mounted external to the agent container in the subscale unit and is internally mounted in the full scale system.

The relative merits of spherical versus cylindrical agent containers were examined. It was decided that both concepts were worthy of investigation during this program. However, due to funding limitations and past experience, the spherical design was chosen as the primary approach.

Both units were designed with primary consideration given to reasonable cost and the development of a reliable, operationally acceptable system. The designs were also influenced by a wide range of variables such as, the pyrotechnic and igniter burn rate, agent vapor pressures, heat of vaporization of agents, corrosiveness at high temperature and variation of agent effectiveness with increasing operating temperatures.

Other capabilities which were considered during the design phase of this program and which are necessary for the acceptance of pyrotechnic extinguishing equipment are as follows:

1. Temperature Cycling Capability

2. Long Term Storage

3. Minimum Envolope

4. Adaptability to Standard Aircraft Electric Power Capacity

5. Adaptability to Statham Analyzer Testing for System Qualification

a. Spherical Design

The final system design shown in Figure 1 consists of a spherical agent chamber, (two welded steel hemispheres), coupled with a burst disc, baffle and outlet assembly and an internally mounted propellant chamber assembly. The design provides sufficient strength to withstand the anticipated vapor and operating pressures and the materials selected. Almar 362 and SAE 4130 steel have been shown to be compatible with the Halon 2403 extinguishing agent. The net volume of the spherical agent chamber is approximately 100 cubic inches.

The spherical shape is an aid in the generation of turbulence in the liquid agent prior to discharge to increase the absorption of heat, and the vaporization and distribution of the agent to insure that the extinguishant is expelled in a gaseous state. This turbulence is also aided by the design and positioning of the baffle assembly. The baffle also prevents impingement of hot gas on the outlet burst disc which was selected to withstand the vapor pressure of the agent at 500° F while bursting at the desired operating pressure.

This design is typical of previously manufactured pyrotechnic extinguisher and inflation system production units in all respects but weight. Since these prototype units must be repeatedly fire tested they have added strength to insure safety during the test program (12,000 psi burst pressure vs. 2,000 psi operating pressure). As such, a true performance comparison with conventional nitrogen units on a system weight effectiveness basis will be presented analytically in a subsequent section of this report.

b. Cylindrical Design

The cylindrical container design is presented in Figure 2. The system design is similar to the spherical design except for the deletion of the baffle assembly. Since the outlet of the propellant chamber is a significant distance (over eight inches) from the container outlet, a baffle would be ineffective as a deflector and unnecessary as regards impingement of hot gas on the burst disc.

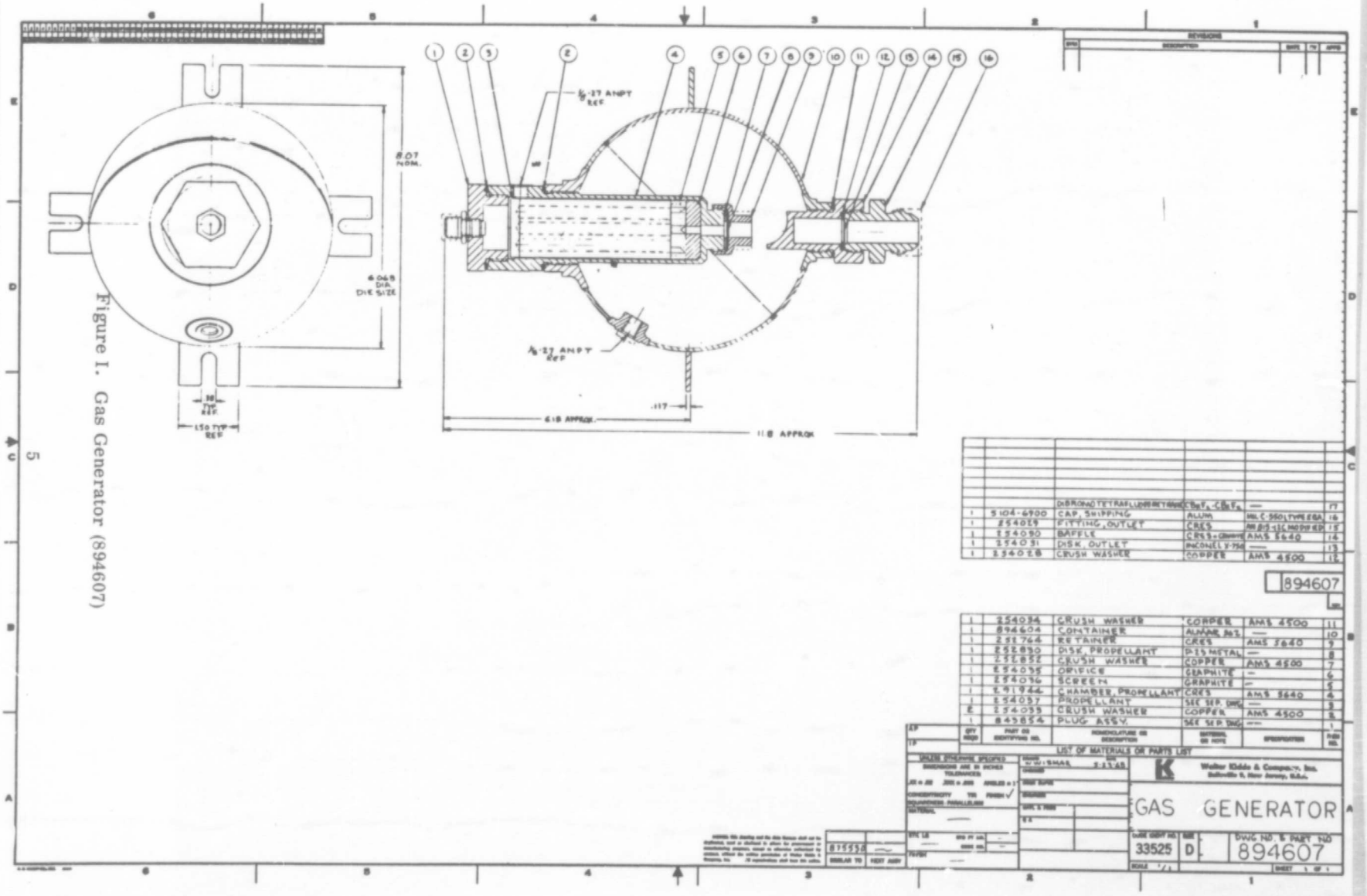


Figure I. Gas Generator (894607)

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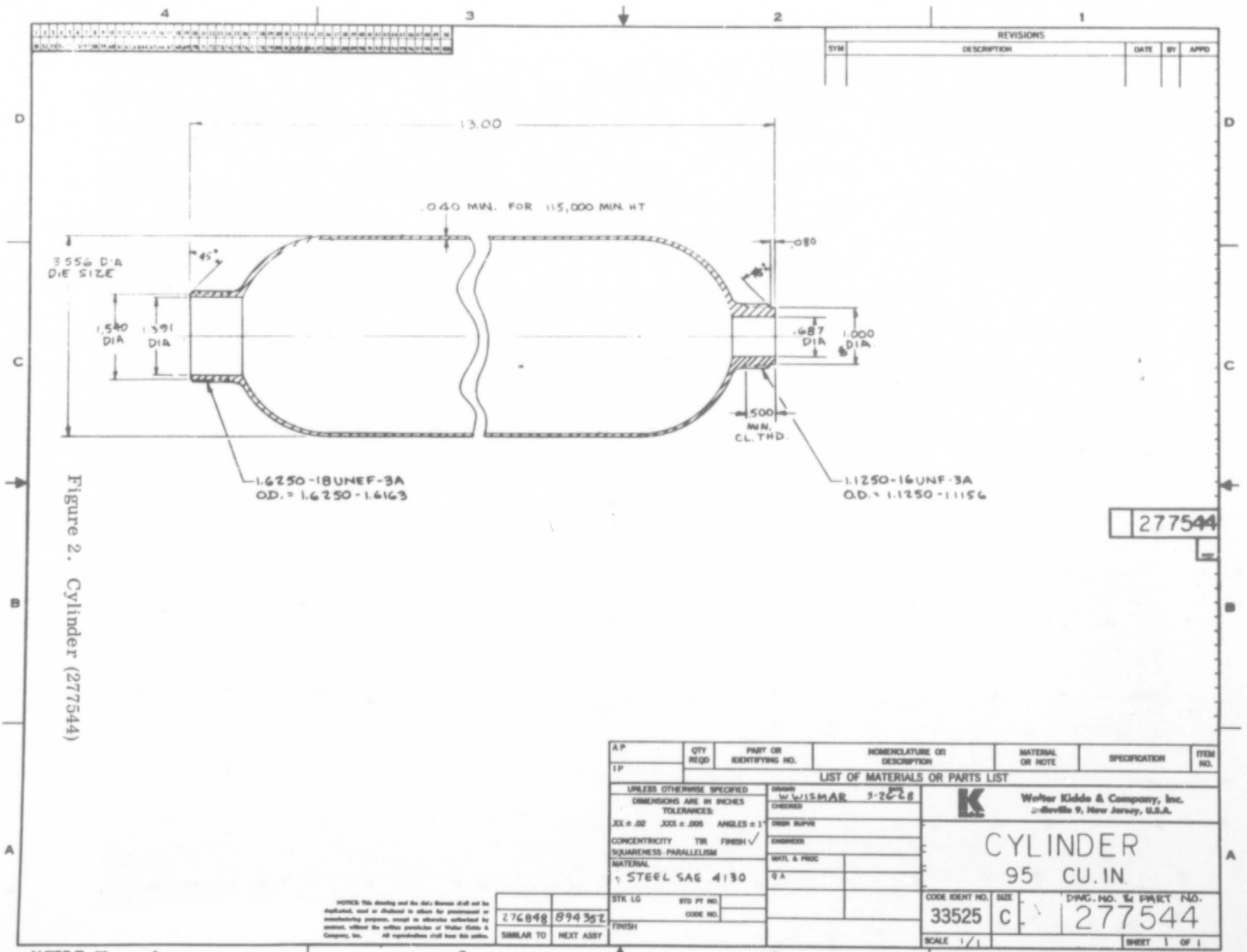


Figure 2. Cylinder (277544)

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The double ended cylinder is deep drawn with spun ends and is relatively inexpensive to manufacture since no welding is required. The system is very light since the chamber is thin walled and the propellant chamber is merely a stainless steel can which is consumed during each run. It is anticipated that in production the cylindrical extinguisher would be a throw-away unit but the system can be refurbished and refired if desired.

c. Gas Generation System

The gas generation technique employed in Kidde pyrotechnic fire extinguishers gives primary consideration to the following parameters:

1. Reliability of ignition after twenty-four hours at the temperature extreme.

2. Relatively flat burning rate vs temperature characteristic.

3. Predictable burn rates over a wide pressure range.

4. Reliability of grain after extended exposure of temperature extremes.

5. Compatibility of products of combustion with selected extinguishing agents.

The pressurization system selected incorporates a squib, ignitor pouch, a sectioned multiperforated grain with a sustainer section, a carbon sleeve, a carbon screen, a carbon orifice and a burst disc assembly. A schematic of the pyrotechnic assembly is shown in Figure 3.

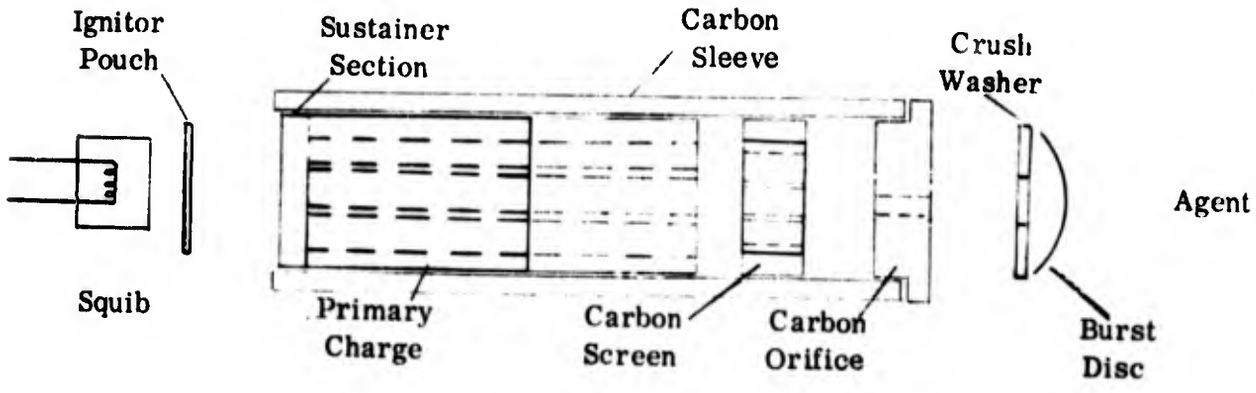


Figure 3. Pyrotechnic System

The squib used in this system was procured from Cartridge Actuated Devices. Inc., Fairfield, N.J. The chemical formulation is similar to that used in the previous subscale program. The cartridge assembly (CAD P/N 029005-1) is thermally stable at 500° F, has a bridgewire resistance of 1.0 to 1.25 ohms, a pin to case resistance greater than 2 megohms at 500 VDC and functions in less than 10 milliseconds at 5 amps. The cartridge has a minimum all fire current of 3.5 amps and has a 1 amp, 1 watt no-fire characteristic.

The squib has dual bridgewires with a standard 4 pin arrangement that mates with a Bendix PC06P-8-4S connector.

The igniter pouch contains one gram of magnesium-teflon powder (Ae Re Co 790). The powder and the solid grain were provided by Aerospace Research Corporation (Ae Re Co), Roanoke, Virginia. The squib ignites the powder which in turn ignites the sustainer section of the solid propellant. One gram of powder is sufficient for ignition no matter how large the solid grain. The propellant characteristics will be discussed in a subsequent section of this report.

The carbon screen provides numerous circuitous flow passages for the hot gases generated by the solid grain. None of the holes are large enough to allow the passage of any solid material which could possibly cause blockage of the orifice downstream. No direct path is provided, so that the burst disc is not subjected to hot gas impingement and possible burn-through prior to rupture at the desired pressure level.

The carbon orifice has a diameter of .152 inches which was selected to provide sufficient back pressure to prevent premature burn-out of the solid grain at the -65° F condition. This size orifice also limits the maximum operating pressure at 500° F to 4000 psi. Early in the program, leakage of the hot gases (approximately 3000° F) around the periphery of the screen and orifice caused degradation of the propellant chamber and in some cases burn-through of the wall. In order to eliminate this problem a carbon sleeve was added to the system. The sleeve runs the full length of the propellant chamber and is connected to the orifice with Selectron Adhesive. Since installation of the sleeve there have been no further reoccurrences of the burn-through problem.

All of the carbon components have been fabricated from commercial graphite. It was originally intended to use pyrolytic graphite but this proved to be unnecessary.

Various candidate metals were considered as burst disc material for the agent outlet disc but the disc used in the propellant chamber remained constant throughout the program. The disc material is gold-clad bronze, .009 inches thick and it bursts over a .500 inch shear edge. Nominal bursting pressure is 1300 psi at 70° F.

## 3. COMPONENT EVALUATION

### a. Propellant Development

The most important property of solid propellant for the given application is its stability at high temperature. The formulation developed by Aerospace Research during the subscale program fulfilled this requirement. The grain selected, Ae Re Co 706D, is a magnesium, teflon, viton, oxamide and barium nitrate compound. While the chemical formulation remained the same for this full scale program the grain geometry had to be modified and more stringent production and quality assurance procedures had to be established.

Analysis and testing of the propellant (Ae Re Co 706D) was conducted with two designs. The first grain design was cylindrical, approximately 1 1/2 inches in diameter and 4 inches long. The second grain,also cylindrical,was about 1 1/4 inches in diameter and 6.2 inches long. Both grain designs could be used in the spherical chamber while the latter grain was suitable for the cylindrical unit.

All of the grains tested were multiperforated with a sustainer section (Ae Re Co 791). The grains were produced in sections, each about 2 inches long. This facilitated the drilling of the longitudinal holes and the tailoring of the propellant for various agent loadings.

These propellant grains with integral sustainer were evaluated by the Bureau of Explosives as to shipping classification. Initially this propellant was given a Class B explosive rating, however, additional testing has resulted in a less severe rating. When packaged in accordance with paragraph 173.154 (a) (8) or (a) (12) of Department of Transportation regulations, the propellant with sustainer is now classed as a flammable solid. The Bureau of Explosives report is included in the Aerospace Research final report.

The Aerospace Research final report on this development of a high temperature propellant subsystem for the full scale pyrotechnic extinguisher is presented as Appendix I of this report.

### b. Agent Analysis

#### 1. Agent Compatibility

The extinguishing agent, Halon 2402 ($CF_2Br - CF_2Br$), shown to be most suitable for use in a high temperature pyrotechnic extinguisher in the subscale effort was also used during this program. The compatibility of $CF_2Br - CF_2Br$ with Almar 362 and various stainless steels was demonstrated in the previous subscale program. Minimal information is available, however, on the compatibility of this agent with titanium. Since titanium is used extensively in the

advanced aircraft for which the 500° F self-pressurizing fire extinguisher was developed, a compatibility test was performed with this material. Included in this test was an analysis of the metal, Havar.

Havar was investigated as a possible burst disc material since its mechanical properties are relatively stable over the required temperature range. It is cobalt-based high strength alloy supplied by Hamilton Precision Metals a division of Hamilton Watch Company. Inconel 600 and Inconel X 750 were also investigated as possible burst disc material but since nickel has already been shown to be compatible with this agent, storage tests were not conducted.

Samples of titanium and Havar were sent to the Freon Products Laboratory of E.I. du Pont deNemours & Company, Wilmington, Delaware, where they were sealed in 10 cc pyrex tubes together with the $CF_2Br - CF_2Br$. The tubes were returned to Kidde and stored at 500° F for sixty (60) days.

After the sixty (60) days storage at 500° F the samples were returned to DuPont for investigation. Their analysis is presented in Table I.

Identification of samples 1 through 10 is as follows:

| | |
|---|---|
| Sample #1, 2 and 3 | Havar (42% Co. 13% Ni, 20% CR) |
| Sample #4, 5 and 6 | Ti - 5 AL - 2.5 SN |
| Sample #7, 8 and 9 | Ti - 6 AL - 4.0 V |
| Sample #10 (Control) | Halon 2402, no metal sample |

Visually all of the three Havar samples appeared to be unaffected. There were, however, differences between the other two sets. The surfaces of samples 4, 5 and 6 were darkened while samples 7 and 9 were unaffected. Sample 8 appeared to be severely attacked. The vast difference in appearance between sample 8 and the other samples in its set indicate the presence of an unknown contaminate in this Pyrex tube. It is felt, therefore, that samples 4 through 7 and 9 are more representative of the compatibility of Titanium and Halon 2402.

An in-house micro-examination of the metal samples was also conducted. All of the samples were bright and shiny originally. After storage, samples 1, 2, 3, 6, 7 and 9 were not corroded. Samples 4 and 5 were slightly corroded, a black film covered their surfaces, while sample 8 was totally corroded.

Microanalysis showed no significant change in microstructure. No inter-granular corrosion was observed in the samples except sample #8. None of the Havar samples showed any effect after the test.

## TABLE I

SEMI-QUANTITATIVE ANALYSIS OF Halon 2402 (GAS CHROMATOGRAPHY [1])

FLUOROCARBON ATTENUATOR PERCENTAGES [2]

| Components Identified (3) | Component Percentages (%) Sealed Tube Samples | | | |
|---|---|---|---|---|
| | 30-1 | 30-4 | 30-7 | 30-10 |
| $CF_2=CF_2$ | 0.05 | 0.01 | 0.14 | 0.19 |
| Unknown | | 0.01 | | |
| $CF_3Br$ | 0.05 | 29.76 | 0.14 | 0.19 |
| $CF_3-CF_2Br$ | | 1.49 | | |
| $CF_2Cl-CF_2Cl$ | | 0.01 | | |
| $CF_2=CFBr$ | | | | |
| $CHF_2-CF_2Br$ | 0.24 | 0.30 | 1.36 | 1.94 |
| $CF_3-CBr=CF_2$ | | 0.60 | | |
| $CF_2Cl-CF_2Br$ | 0.02 | 0.06 | 0.07 | 0.10 |
| $CF_3-CF=CBr-CF_3$ | | 0.06 | | |
| $CF_2Br_2$ | 0.02 | | 0.07 | 0.10 |
| $CF_2Br-CF_2Br$ | 97.17 | 59.80 | 95.50 | 97.09 |
| $CF_2Br-CF_2-CF_2Br$ | | 0.15 | | |
| $CFBr=CFBr$ | 0.49 | 0.30 | | |
| $CHFBr-CF_2Br$ | 0.49 | 0.30 | | |
| $CF_3-CF_2-CF_2-CF_2Br$ | 0.49 | | | |
| $CF_2Br-CF_2-CF_2-CF_2Br$ | | 0.30 | | |
| $CFBr=CF-CF_2Br$ | 0.49 | 0.30 | | 0.39 |
| $CF_2Br-CF=CF-CF_2Br$ | | 0.60 | | |
| $CHCl=CCl_2+CH_2=CH-(CF_2)_4-Br$ | | | 2.72 | |
| $CF_2=CBr-CBr=CF_2$ | 0.49 | 5.95 | | |
| $CF_2Br-CF_2-CF_2-CF_2Br$ | | | | |
| $CF_2Br-CF_2-CFBr_2$ | | | | |

TABLE I (Cont)

SEMI-QUANTITATIVE ANALYSIS OF Halon 2402 (GAS CHROMATOGRAPHY [1])

FLUOROCARBON ATTENUATOR PERCENTAGES [2]

(1) Gas chromatographic analyses were run in a 6 meter DC-200 oil column. Temperature programing cycle was between room temperature and 150°C at 6°C/minute. Program temperature start at 600 seconds.

(2) Component percentages were calculated based on peak attenuator values, and were calculated as follows:

$$\% = \frac{\text{component attenuator scale x 100}}{\text{total of all component attenuator settings}}$$

(3) Component identifications were made by Time of Flight Mass Spectrometry in eluting gas chromatographic fractions.

2. Agent Breakdown

Halon 2402 has been shown to be compatible with most of the materials it is likely to come into contact with aboard advanced aircraft. In operation, however, it will contact nacelle and engine hardware after mixing with the hot gases produced by the solid propellant. It is therefore desirable to know the products of combustion, thermal breakdown, and their possible effect on aircraft components.

In order to determine these products a pyrotechnic extinguisher was fired with the agent chamber outlet blocked in order to retain the liquid agent and propellant mix. A sample of this mix was then submitted to DuPont for analysis. This analysis appears in Table II.

This data shows minimal agent breakdown (approximately 1.5%). The components produced by the hot gas and agent mixture are for the most part other extinguishing agents. Most of these are similar to the Halon 2402 and were shown to be compatible with various metals in the previous subscale program.

TABLE II

SEMI-QUANTITATIVE ANALYSIS OF Halon 2402 (GAS CHROMATOGRAPHY [1] FLUOROCARBON ATTENUATOR PERCENTAGES [2] AFTER FIRING OF AeReCo 706 D

| Components Identified (3) | Retention Time Sec. | Control Sample | After Reaction With Solid Grain Charge |
|---|---|---|---|
| $CF_2=CF_2$ | 173 | 0.20 | 0.10 |
| Unknown | 198 | | |
| $CF_3Br$ | 215 | | |
| $CF_3-CF_2Br$ | 262 | | |
| $CF_2Cl-CF_2Cl$ | 409 | | |
| $CF_2=CFBr$ | 422 | | 0.05 |
| $CHF_2-CF_2Br$ | 502 | | 0.05 |
| $CF_3-CBr-CF_2$ | 585 | | |
| $CF_2Cl-CF_2Br$ | 735 | 0.10 | |
| $CF_3-CF=CBr-CF_3$ | 805 | | |
| $CF_2Br_2$ | 877 | | 0.49 |
| $CF_2Br-CF_2Br$ | 1120 | 98.71 | 97.02 |
| $CF_2Br-CF_2-CF_2Br$ | 1348 | | 0.19 |
| $CFBr=CFB4$ | 1454 | | 0.05 |
| $CHFBr-CF_2Br$ | 1500 | | 0.10 |
| $CF_3-CF_2-CF_2-CF_2Br$ | 1566 | | 0.19 |
| $CF_2Br-CF_2-CF_2-CF_2Br$ | 1588 | | |
| $CFBr=CF-CF_2Br$ | 1633 | | 0.10 |
| $CF_2Br-CF=CF-CF_2Br$ | 1737 | | 0.10 |
| $CHCl=CCl_2+CH_2=CH-(CF_2)_4-Br$ | 1800 | | |
| $CF_2=CBr-CBr=CF_2$ | 1825 | | 0.10 |
| $CF_2Br-CFBr_2$ | 2065 | | 0.97 |
| $CF_2Br-CF_2-CF_2-CF_2Br$ | 2160 | 0.99 | |
| $CF_2Br-CF_2-CFBr_2$ | 2268 | | 0.49 |
| Fluoride Ion, PPM (4) | | 0.1 | 438 |
| Bromide Ion, % (5) | | 0.001 | 0.13 |

TABLE II (Cont)

SEMI-QUANTITATIVE ANALYSIS OF Halon 2402 (GAS CHROMATOGRAPHY [1])
FLUOROCARBON ATTENUATOR PERCENTAGES [2] AFTER FIRING OF AeReCo 706D

(1) Gas chromatographic analyses were run in a 6 meter DC-200 oil column. Temperature programing cycle was between room temperature and 150°C at 6°C/minute. Program temperature started at 600 seconds.

(2) Component percentages were calculated based on peak attenuator values, and were calculated as follows:

$$\% = \frac{\text{component attenuator scale x 100}}{\text{total of all component attenuator settings}}$$

(3) Component identifications were made by Time of Flight Mass Spectrometry in the eluting gas chromatographic fractions.

(4) Fluoride ion was determined using an ion specific electrode.

(5) Bromide ion was determined by argentimetric titration.

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## SECTION III

## TESTING

### 1. GENERAL

Before extensive fire testing was performed with the complete pyrotechnic extinguishing system, numerous functional tests were conducted in-house with the various subsystems.

The propellant igniter subsystem was extensively tested to validate the Aerospace Research experimental data and to aid the system integration of the squib, gas generator and agent chamber assembly. The effect of the burst disc on the final pressure was also determined.

Vapor pressure versus temperature tests were performed at various density loadings with $CF_2Br$-$CF_2Br$ (Halon 2402) to generate technical information and to aid sizing of the burst disc. Storage tests were also performed with the solid grain in order to estimate its useful life.

#### a. Propellant-Igniter Tests

The first phase of this portion of the program was to confirm AeReCo results in Kidde hardware. Initially, performance tests were conducted by AeReCo at ambient, -65°F and 500°F on the 1.25 inch diameter grains. The data from these tests are shown plotted in Figure 4. Additional grain tests were run at the temperature extremes to insure that there is relatively constant output. This data is presented in Appendix I.

The AeReCo tests were performed with 6.2 inch long grains. This length provided more grain weight than necessary since it was sized to handle five pounds of agent and due to fire limitations only four pounds was required. The in-house tests conducted to validate the AeReCo results were performed with 1.25 and 1.50 inch diameter grains of varying lengths (4.0 to 6.2 inches). The orifice area was varied relative to the changes in grain area according to the burning surface to throat area ratio;

$$K_N, \frac{\text{Burning Area}}{\text{Throat Area}}$$

to maintain a maximum pressure of about 3000 psi at 70°F. Since the pressure is directly proportional to $K_N$ for a constant temperature it remains constant if the ratio is held constant.

In general, there was very good agreement between the AeReCo and in-house propellant tests conducted at room temperature. The in-house data is presented in Table III

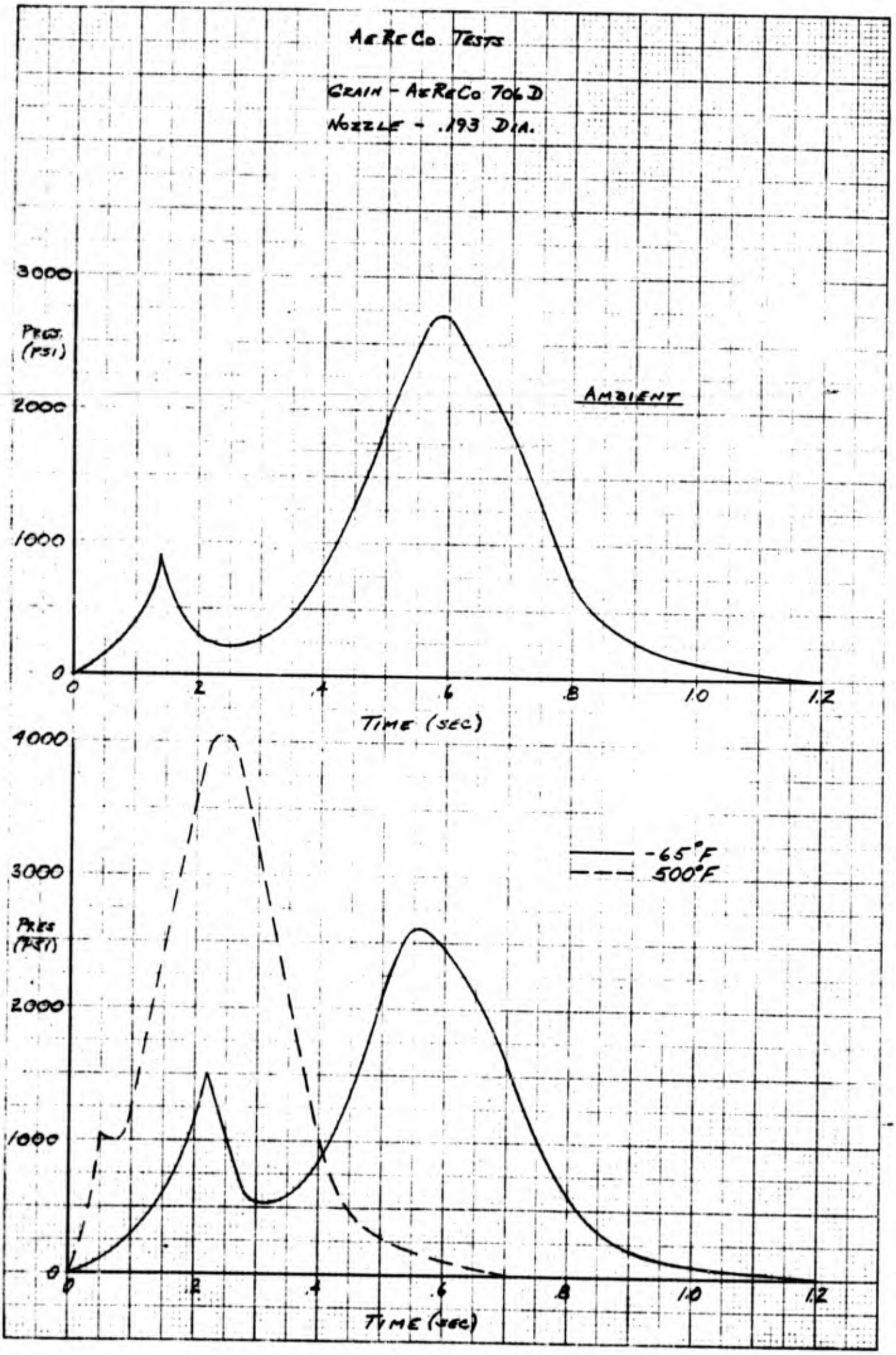


Figure 4. Propellant Grain (AeReCo 706) Pressure Generation Test

TABLE III

GAS GENERATOR TESTS

WITH

AEROSPACE RESEARCH

706D GRAIN AND INTEGRAL 791 SUSTAINER

| TEST NO. | TEMP. (°F) | GRAIN LENGTH (in.) | GRAIN DIA. (in.) | ORIFICE (in.) | PEAK PRESSURE | TIME TO PEAK | DECAY TIME (sec.) | REMARKS |
|---|---|---|---|---|---|---|---|---|
| 082901 | Ambient | 6.2 | 1.25 | .225 | 1400 | .08 | -- | Hang fire, only sustainer burned. |
| 090401 | Ambient | 6.2 | 1.25 | .185 | 2900 | .50 | .54 | Similar to AeReCo data. |
| 090402 | Ambient | 4.2 | 1.25 | .155 | 3100 | .53 | .52 | Similar to AeReCo data. |
| 090403 | Ambient | 4.2 | 1.25 | .155 | 2800 | .48 | .58 | Complete assembly, premature discharge, burn thru of baffle. |
| 093001 | Ambient | 4.2 | 1.50 | .225 | 2600 | .51 | .49 | Ceramic coated baffle. |
| 093002 | Ambient | 4.0 | 1.50 | .225 | 2900 | .53 | .52 | Molybdenum coated baffle |
| 102201 | Ambient | 4.1 | 1.25 | .155 | 2900 | .50 | .57 | Filled holes with more grain |
| 102401 | -65 | 4.1 | 1.25 | .155 | 2400 | .62 | .52 | Graphite baffle - no burn |
| 102501 | Ambient | 4.1 | 1.25 | .155 | 2800 | .54 | .54 | Thru-Grain Wt. 106 gms |
| 110701 | -65 | 4.1 | 1.25 | .155 | 2600 | .65 | .55 | Grain alone - Wt. 105 gms |
| 011301 | +500 | 4.1 | 1.25 | .155 | 3600 | .41 | .49 | Peak pressure acceptable |
| 011302 | Ambient | 4.2 | 1.25 | .155 | 2400 | .49 | .79 | Grain Wt. - 105 gms |
| 020901 | Ambient | 4.1 | 1.25 | .155 | 3000 | .51 | .54 | Grain Wt. - 115 gms<br>No indication of erosion of propellant chamber 4" carbon sleeve. |

and a few of the runs are plotted in Figure 5. The tests are designated by numbers indicating date (month and day) and test sequence for that date.

Test 082901, the initial firing, was conducted at room temperature using 1 gram of AeReCo 791 ignition powder and the 1.25 inch diameter grain, 6.2 inches long. A larger orifice was used than in the AeReCo tests (.225 vs. 193 inches) in an effort to operate at a lower peak pressure. The .225 orifice proved too large, insufficient back pressure was provided and a hang fire resulted.

Test 090401 was conducted with a .185 inch orifice and run 090402 used a 4.2 inch long grain with a .155 inch orifice. Both runs appeared similar to one another and the AeReCo data. The 6.2 inch grains were run in a test bomb while the 4.2 inch grain was run in the propellant chamber designed for the spherical extinguisher. All of the tests were performed with carbon orifices and screens and with a burst disc (nominal rupture pressure - 1000 psi).

A complete assembly was then tested (Run 090403) with 4 pounds of agent. The pressure data and discharge appeared normal. Only one functional problem was encountered.

The steel baffle at the agent chamber outlet was severely eroded due to impingement of the hot gas from the propellant chamber.

In order to alleviate this problem two baffles were coated, one with molybdenum the other with ceramic (Runs 093001 and 093002). Neither coating proved acceptable as significant erosion continued. Since the baffle does not see any load during the discharge cycle, the upper curved section was fabricated from graphite and connected, using selectron, to the steel threaded section. This design has proved to be acceptable as little or no erosion was discernible during the remainder of the test program.

The latter runs were conducted with 1.50 inch diameter grains and the resultant pressure traces were similar to the comparable AeReCo data. The agent discharge appeared normal and occurred at the desired burst pressure. Selection of the burst disc is detailed in a subsequent section of this report.

As a result of these tests and fire tests conducted at NAFEC, it was decided that the 1.25 inch diameter grains were more effective and easier to accommodate in the spherical unit's propellant chamber than the 1.5 inch diameter grain. In a 4.1 inch length, however, this grain does not provide enough heat at the -65°F condition to raise the agent to the desired vapor pressure. Plugs of solid grain were therefore inserted in the longitudinal holes of the propellant. Runs 102201, 102401, 102501 were conducted with this modified grain design. The pressure traces were similar to those runs conducted previously and the remainder of the test program was performed with the modified propellant.

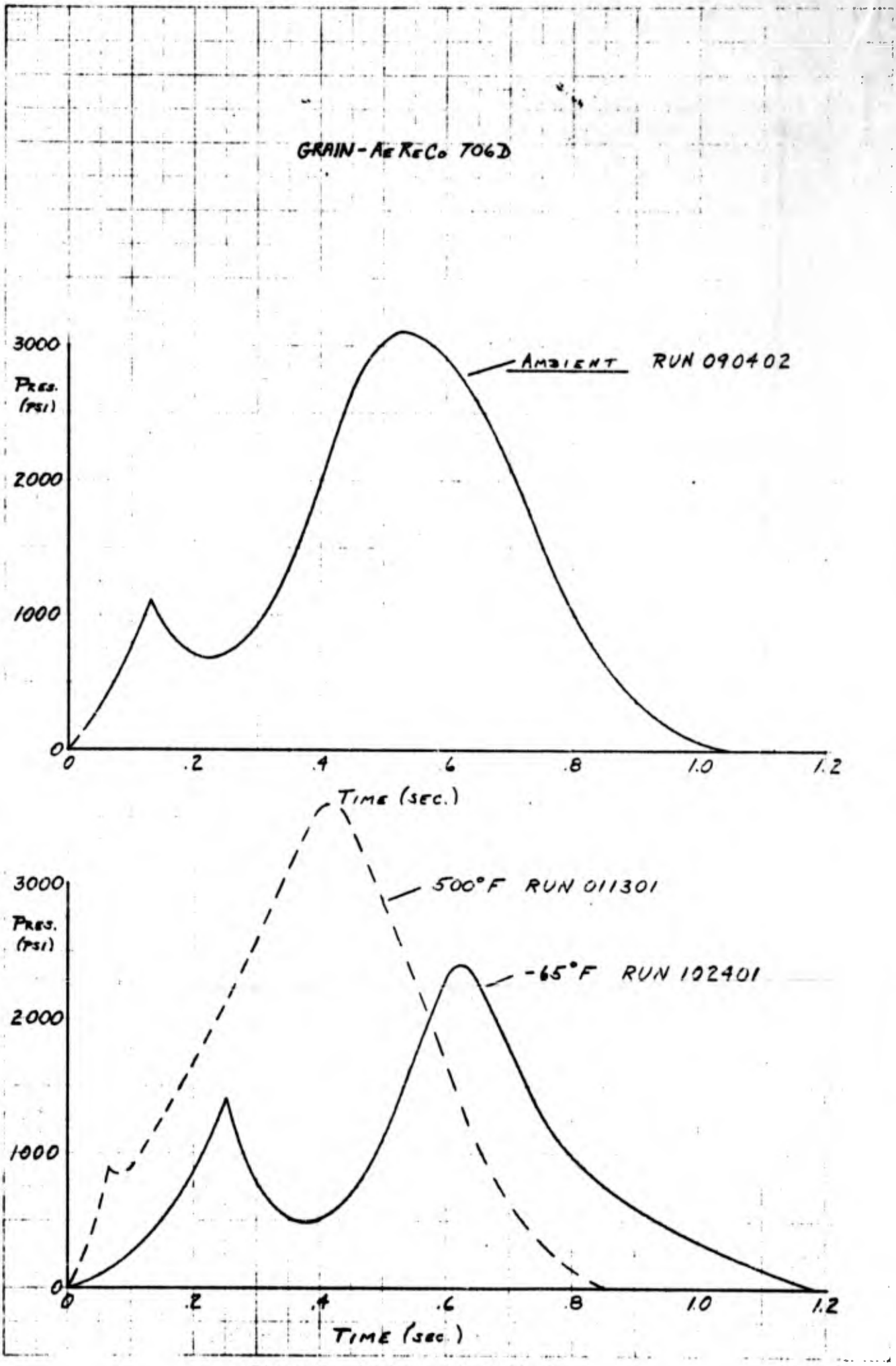


Figure 5. In-House Grain Tests

In-house testing consisted of both grain tests and complete discharge tests. The purpose of these preliminary tests was to determine the proper orifice and outlet sizes to select the proper grain design and to correct any functional problems that might occur. Once the orifice and outlet were sized, the rupture pressures of the propellant and agent chamber burst discs were selected to provide the proper discharge rate at ambient conditions.

b. Burst Disc Tests

In the previous subscale development program, it was difficult to maintain constant discharge rates over the -65°F to 500°F range. As ambient temperature changed, agent vapor pressure and the rupture pressure of the outlet burst disc varied divergently. As a result, discharge rates over the temperature range were erratic.

In an attempt to overcome this problem, two steps were taken. The capacity (100 cu. in.) of the agent chamber in the full scale unit was selected to minimize the agent vapor pressure excursion over the temperature range and various stable metals were investigated as possible burst disc material.

The candidates were Havar, a high strength cobalt based alloy, Inconel 600 and Inconel X750. A mounting fixture was fabricated and burst disc tests were conducted over a -65°F to 500°F temperature range. The test results were as follows:

| | BURST PRESSURE | | |
|---|---|---|---|
| TEMP (°F) | HAVAR | INCONEL 600 | INCONEL X750 |
| -65 | 6300 | 2450 | 3200 |
| -65 | 6250 | 2450 | 3200 |
| 72 | 5600 | 2200 | 2750 |
| 72 | 5600 | 2200 | 2850 |
| 450 | 4400 | 1750 | 2500 |
| 450 | 4400 | 1850 | 2600 |

Based on this data the Inconel X750 appeared to be the most suitable burst disc material. The rupture pressure of the Havar is 25% lower at 500°F than at 70°F and is completely unacceptable. The Inconel 600 would be suitable but the X750 is more stable between 70°F and 500°F.

All of the tests performed during this program used the Inconel X750 material as an agent outlet burst disc unless otherwise noted. Nominal bursting pressure is 1700 psi at 70° F.

The propellant chamber disc remained constant throughout the test program. The disc material is gold-clad bronze and the nominal burst pressure at 70° F is 1300 psi as mentioned previously.

c. Vapor Pressure Tests

In anticipation of the expanding use of $CF_2Br$-$CF_2Br$, a need exists for design curves from which containers for this agent may be designed or selected for specific applications. Most useful and desirable is a graphical presentation of vapor pressure - temperature data for various filling densities.

Experimental data was acquired during the previous subscale program using the pyrotechnic agent chamber as the pressure vessel. Knowledge of the actual vapor pressure levels to be encountered is necessary in order to determine the burst discs to be provided, for the pyrotechnic unit. The vapor pressure-temperature data for various filling densities is presented in Figure 6. The accuracy of this experimentally obtained data was marginal since the quantities of agent used and the capacity of the agent chamber were minimal and small differences were sizable percentage errors. This effort was repeated during this full scale program to generate additional and more accurate data.

The dashed line present on the original pressure-temperature curve represents the full scale data acquired during this program.

d. Long Term Exposure Tests

In-house exposure tests were conducted on subscale samples of the AeReCo 706D propellant. The grain exhibited no degradation in performance after exposure to 450° F for 400 hours nor after a thermal shock test (3 cycles, -40° F to 250° F).

Figure 7 is a typical temperature-time plot of propellant life. The usable life of a propellant may be shown as a straight line relationship when the natural log of time is plotted against the reciprocal of the absolute temperature.

The straight line, when completely defined, separates the points of acceptance ( O ) from the points of failure ( X ). However, with the AeReCo 706D propellant, failures have not as yet been experienced. At present, this grain has an estimated life of at least one year at 400° F.

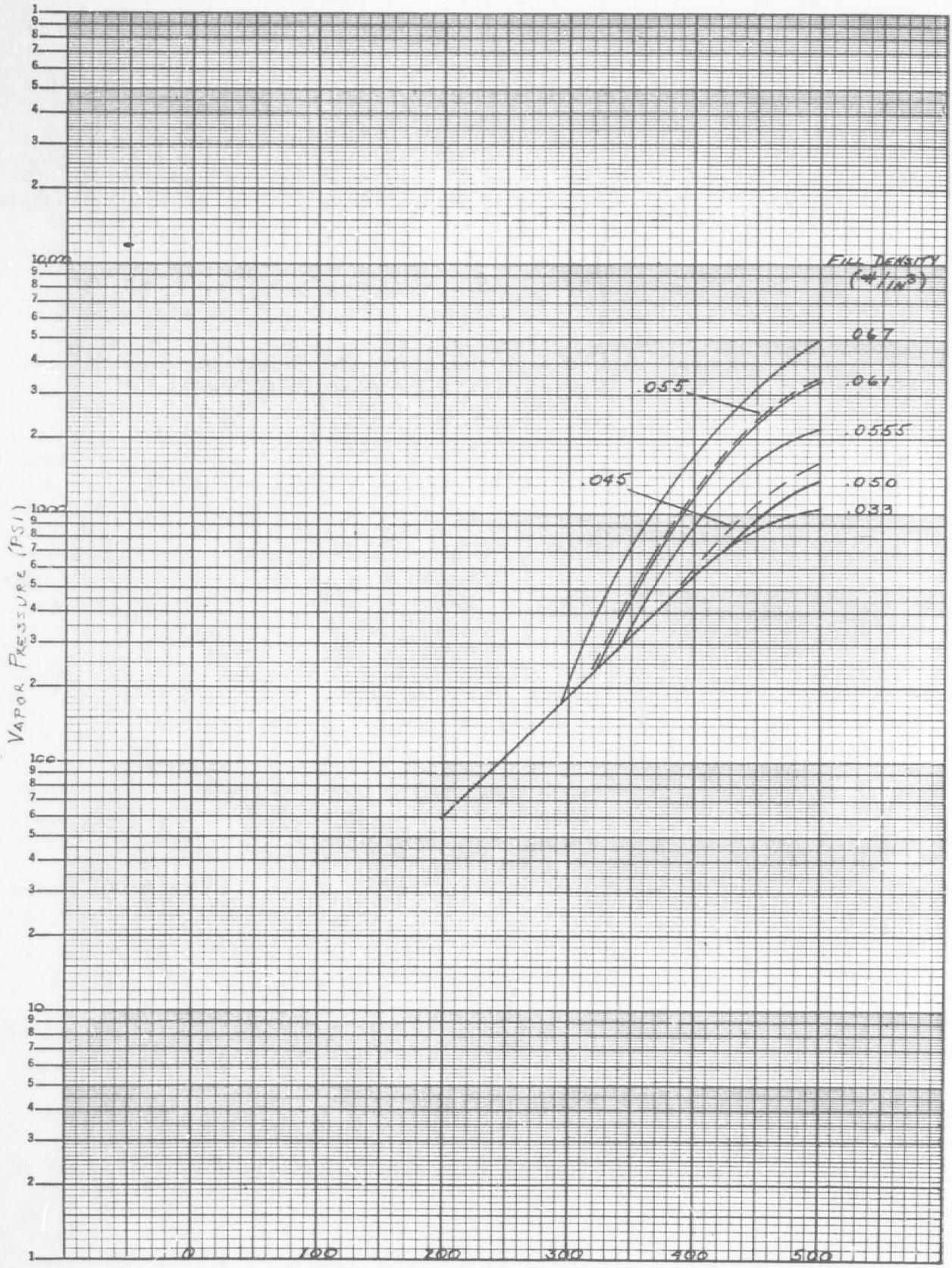


Figure 6. Halon 2402 Vapor Pressure vs Temperature

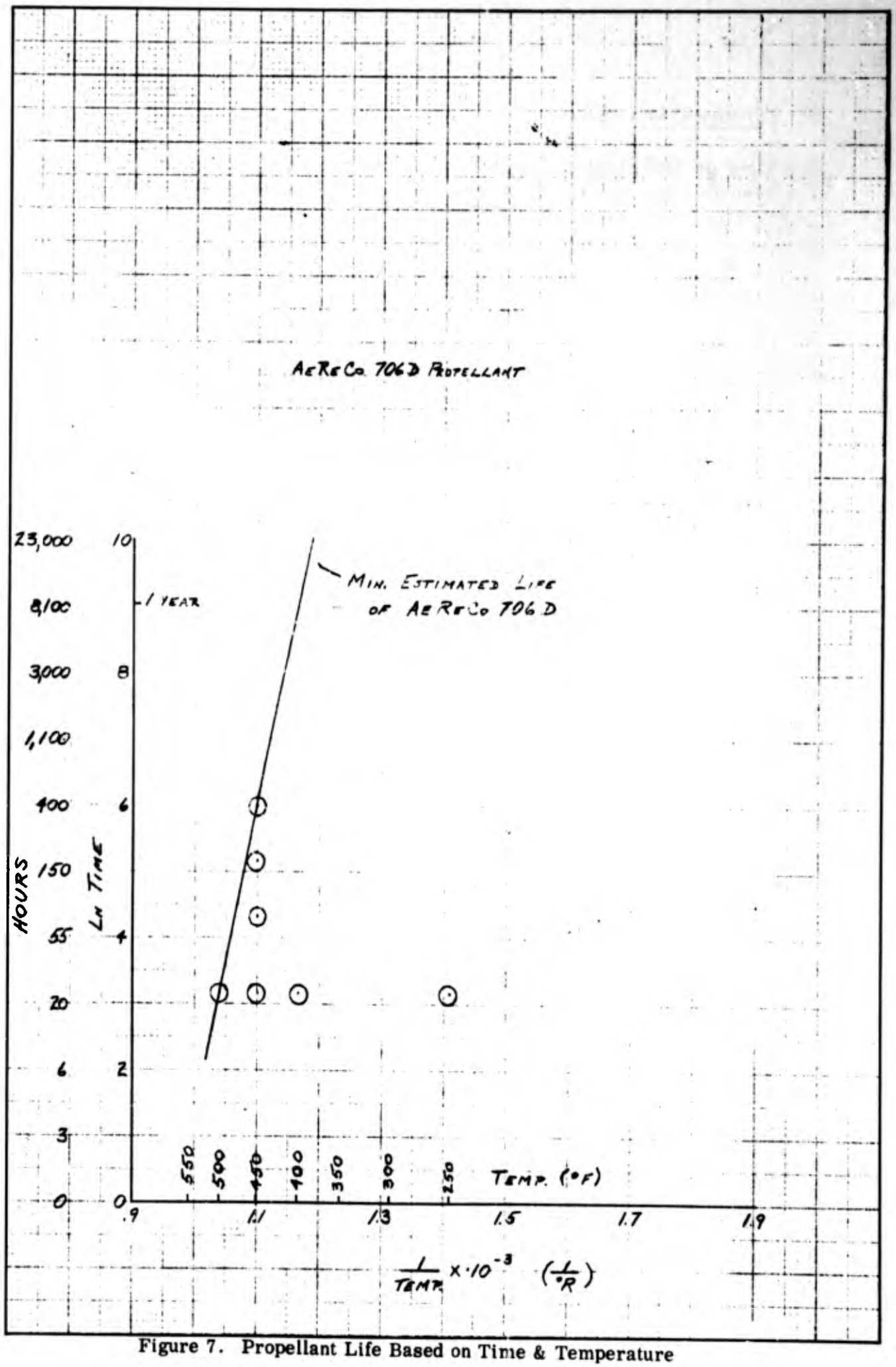


Figure 7. Propellant Life Based on Time & Temperature

e. Cylindrical Unit Testing

Time and funding prevented a complete development and fire test program to be conducted with the cylindrical design as well as the spherical unit. However, functional tests were conducted in-house with the cylindrical unit and a preliminary analysis indicates that this system offers great growth potential. This potential is due to the simplicity of the unit and the considerable savings in system weight and cost that may be effected.

The initial test with this unit Run 042901 was conducted with 4 pounds of agent and a subscale grain remaining from the previous program. Ignition was achieved and the grain burned completely reaching a maximum pressure of 3000 psi in the propellant chamber. However, the maximum agent chamber pressure reached, 1000 psi, was insufficient to rupture the outlet disc.

Post test inspection showed that all components functioned normally except the disc, which bowed but did not rupture. The shear edge was dull but the primary cause of the lack of discharge was an insufficient quantity of grain.

The test was repeated, Run 011302 (Table III) with full scale grains (1.25 inch diameter, 4.2 inches long) and the system discharged conventionally. Sufficient pressure was developed to rupture the outlet disc and 4 pounds of agent were discharged in 0.8 seconds. The pressure traces and discharge rates were very similar to those achieved with the spherical design using the same amount of grain and agent.

2. FIRE TEST FACILITY

While subsystem tests were being performed, a parallel program was underway at the National Aviation Facilities Experimental Center (NAFEC) to prepare the test facility for the conduction of a fire test program. The preparation of the test site and the fire testing was performed by NAFEC personnel under an Air Force contract with the AF Aero Propulsion Laboratory.

A simulated nacelle in the Equipment Safety Test Laboratory was modified so that "Standard" test fires could be produced repeatedly based on the requirements of the full scale pyrotechnic fire extinguishing program. The desired "Standard" test fire was one that could be extinguished with five pounds of agent, discharged from a nitrogen pressurized cylinder, but would not be extinguished by four pounds of agent.

The test nacelle is fifty inches in diameter and twelve feet long including the bellmouth section and simulates the configuration and environment of a turbine engine in flight. A simulated engine body inside the nacelle is thirty six inches in diameter and eight feet long. Five one-inch angle ribs are normally used inside the nacelle to provide a degree of roughness. Air flow is usually created by drawing air through the nacelle with a one-hundred

horsepower electric-driven fan. The flow was regulated to provide three pounds per second by enclosing the forward end with a 1/4 inch thick acrylic plastic sheet in which 89, 1-1/8" diameter holes were cut. The plastic sheet is located in a bellmouth entrance ahead of the simulated nacelle.

A fuel nozzle was located on the port horizontal center line, 35 inches aft of the forward edge of the nacelle. This nozzle directed a stream of JP-4 jet fuel downward at a 45° angle. The fuel rate in gallons per minute was varied in an effort to provide the desired "standard" fire.

The system through which the agent was discharged consisted of an AN "T" fitting at the agent container bonnet and two three quarter inch diameter stainless steel lines each seven feet long. The agent container bonnet was mounted externally on top of the nacelle mock-up and the steel lines were also outside of the mock-up until they terminated as nozzles in the sides of the nacelle. The nozzles are located six inches aft of the forward edge of the nacelle. The nozzle size and position were varied to change agent distribution and coverage to aid in the development of the desired "standard" fire.

Four 224 cu. in. nitrogen pressurized extinguishers were provided by Kidde to NAFEC personnel. These units were used to "standardize" and calibrate the test fire. Burst discs and cartridges required for recharges were furnished by Kidde and the nitrogen and agent were provided by NAFEC.

Preliminary fire testing indicated that a five pound fire would severely handicap the electric motor if left at the aft of the nacelle. The one-hundred horsepower electric-driven fan was then relocated at the entrance of the test nacelle in order to increase the size of the test fire to accommodate the larger agent loading to be used during this full scale program.

A recirculation problem was encountered due to the rearrangement of the electric-driven fan. This necessitated the construction of a partition at the fan outlet and bellmouth interface.

When the recirculation problem was corrected numerous fire tests were conducted in an effort to increase the size of the "standard fire". In the previous subscale program the "standard fire" was extinguished with 2 lbs of agent. In this program it was desired that the "standard fire" be extinguished with 5 lbs of agent.

Fuel flow was more than doubled and the other parameters, such as, air flow were also changed but the largest fire developed was still extinguished with 3 lbs of agent.

In an another effort to increase the agent requirement circumferential and longitudinal ribs were added to the center body of the test article by NAFEC personnel. Fire testing with this configuration resulted in the development of a significantly large fire, one that was extinguished with 5 pounds of agent but not with 4 pounds, however, this fire was not repeatable for more than a few days. The largest repeatable fire developed was one that was extinguished with 4 pounds of agent but not with 3 pounds. Fire testing with this configuration and "standard fire" was continued for the remainder of the test program.

## 3. TEST PROCEDURE

The nacelle wall in the vicinity of the fire was preheated to above 300°F by short duration fires. The nacelle was permitted to cool until the temperature lowered to 300°F, then, the standard test fire was started. The start consisted of initiating fuel flow at the desired rate and providing ignition. Fuel flow was continued while the test fire burned for twenty seconds, approximately the time it takes a pilot to detect and react to a fire, at which time the extinguishing agent was discharged. The results were observed and the data recorded, after which the fuel to the nacelle cavity was shut off.

Prior to running any comparative tests with the pyrotechnic extinguishing units, two runs would be conducted with $CF_3Br$ discharged from a 224 cubic inch spherical container pressurized to 600-650 psi with nitrogen. These runs were performed to confirm that the fire produced that particular day was consistent with previous standard fires. The nitrogen charged bottles were always fired at room temperature.

The facility and test procedure initially provided a fire condition which required four pounds of monobromotrifluoromethane ($CF_3Br$) extinguishing agent to extinguish the fire. Three pounds of agent would not extinguish the fire under the same test condition. This size fire and results were demonstrated repeatedly with consistency. Increased fire conditions were not as easy to maintain.

Once "standard" fire conditions had been confirmed, a pyrotechnic unit was connected to the discharge system and the following procedure was adhered to for each test:

1. The firing system and associated wiring were checked for continuity.
2. The data recording equipment was zeroed and put on remote control.
3. Air flow was maintained at three pounds per second.
4. The nacelle hardware was heated to test temperature.
5. The fuel line valve was opened.
6. The ignition system was turned on.
7. When flame was visible, the ignition system was turned off.
8. After 20 seconds, the recorders were turned on and the pyrotechnic extinguishing system was electrically actuated.
9. After results were noted, the fuel valve was closed and the equipment shut down.

## 4. INSTRUMENTATION

### a. Facility Instrumentation

Numerous thermocouples were attached at evenly distributed points on the outer engine surface to measure engine surface temperatures while testing. The output of the thermocouples was fed through a position selector switch to a temperature recorder.

An inclined manometer was used to monitor air flow. The fuel flow was monitored with a flow meter and the fuel pressure was recorded on a pen recorder. An eight channel recorder was also provided by NAFEC to handle the pyrotechnic extinguisher's instrumentation requirements.

### b. Extinguisher Instrumentation

Pressure data was recorded on both the pyrotechnic and agent chambers. Two transducers were used to acquire the data, a 10,000 psi model was used on the pyro chamber and a 5,000 psi model was used on the agent chamber. The data was recorded on the eight channel recording equipment provided. A thermocouple was installed in the bonnet to measure the temperature of the agent at discharge and thermocouples were also installed in the discharge lines at the nacelle inlet to measure the agent temperature just prior to distribution into the nacelle. The nitrogen charged extinguishing units were not instrumented.

## 5. TEST RESULTS

In general the complete pyrotechnic extinguishing units tested in-house and at NAFEC functioned satisfactorily with all quantities of agent used. The only functional difficulties that did occur were some squib burn out and propellant chamber burn-thru problems and non-rupture of the agent outlet disc at the -65°F condition. All of these problems were corrected.

During the early testing at NAFEC, runs 010803 and 010804, a leak developed through the glass seal in the top of the squib of the pyrotechnic unit. As a result, chamber pressure was not maintained at the desired level and agent discharge was not accomplished. This problem was experienced at NAFEC during the previous program. The NAFEC power supply was investigated and found to be supplying excessive amperage to the squib once again. Replacement of a resistor in the NAFEC circuit corrected this problem. (Starting w/run 010805).

During runs 012103, 012704 and 020603 a hole was burned through the wall of the propellant chamber. Various carbon sleeves to shield the wall were tested until an acceptable configuration was determined. Additional details are presented in the following section on the room temperature tests.

The non-rupture problems experienced with the agent outlet discs at -65°F will be discussed in a subsequent section of this report.

A summary of all tests performed under this program is presented in Table IV.

a. Room Temperature Tests

During the initial room temperature tests a "standard" fire was defined as one which is always extinguished with four (4) pounds of $CF_3Br$ (Halon 1301) but not-with three (3) pounds of $CF_3Br$. Marginal success is achieved with three and one half (3 1/2) pounds of agent.[3] The primary characteristics of the "standard" fire in the NAFEC nacelle mock-up are:

| | |
|---|---|
| Air Speed | 3.00 ± .10 lb/sec |
| Fuel Pressure | 28.0 ± 2.0 psig |
| Fuel Flow | 2.70 ± .10 gal/min. |

Initial test results with the pyrotechnic extinguisher were excellent. The "standard fire" was extinguished in five of the first six tests performed. In the only "failure" run 120403, the distribution system was changed to determine its effect. The result of this change was that the majority of the agent was discharged externally rather than on the fire.

Due to the difference in initial discharge pressures, approximately 600 psi for the nitrogen units and 1700 psi for the pyrotechnic units, it was evident that a distribution system suitable for one extinguisher was not necessarily suitable for the other.

During tests 112601, 112602 and 120404 to 120406, the distribution system used appeared to be more favorable to the pyrotechnic unit as evidenced by runs 120405 and 120406 in which the "standard fire" was easily extinguished with three and a half (3.5) pound of agent. The distribution system was changed for run 120403 and while the nitrogen system with four (4) pounds of agent could still extinguish the fire, the pyrotechnic unit could not.

The primary concern of the testing that followed the first six tests at NAFEC was to determine a "standard" distribution system that allowed for a valid comparison between the nitrogen units and the pyrotechnic extinguisher. The tests performed after 120406 were with different distribution systems but the discharge rates of the pyrotechnic unit also varied due to these changes (discharge nozzle size and direction were varied), causing a difference in extinguishing efficiency. Selection of a standard distribution system was handicapped due to the discharge rate changes.

## TABLE IV

## TEST SUMMARY

## PROJECT 4599 - AF-33615-68-C-1121

| Test No. | Temp. | Agent & Qty | (lb) | PROPELLANT CHAMBER | | | AGENT CHAMBER | | | Fire Exting. | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Peak Press (psi) | Time to Peak (sec) | Total Run Time (sec) | Peak Press (psi) | Time to Peak (sec) | Decay Time (sec) | | |
| 112601 | Room | Halon 2402 | 4.0 | 2500 | .47 | 1.60 | 2000 | .73 | .87 | Yes | |
| 112602 | Room | Halon 2402 | 4.0 | 2450 | .47 | 1.60 | 2100 | .83 | .77 | Yes | |
| 120403 | Room | Halon 2402 | 4.0 | 3100 | .44 | 1.60 | 2100 | .81 | .79 | No | Change in Dist. system |
| 120404 | Room | Halon 2402 | 4.0 | 2700 | .47 | 1.70 | 2200 | .90 | .80 | Yes | |
| 120405 | Room | Halon 2402 | 3.5 | 3500 | .53 | 1.60 | 1700 | .68 | .92 | Yes | |
| 120406 | Room | Halon 2402 | 3.5 | 1700 | .55 | 2.00 | 1600 | 1.20 | .80 | Yes | |
| 121804 | Room | Halon 2402 | 4.0 | 3200 | .50 | 1.55 | 2250 | .75 | .80 | No | Changes in Dist. system |
| 121805 | Room | Halon 2402 | 4.0 | 2900 | .47 | 1.43 | 1850 | .63 | .80 | No | |
| 010803 | Room | Halon 2402 | 4.0 | 1000 | .20 | -- | 2100 | -- | -- | -- | No discharge due to facility electrical problem |
| 010804 | Room | Halon 2402 | 4.0 | 1500 | .25 | -- | 1800 | -- | -- | -- | |
| 010805 | Room | Halon 2402 | 3.5 | 3000 | .40 | 1.40 | 1650 | .70 | .70 | No | |
| 010806 | Room | Halon 2402 | 3.5 | 3200 | .45 | 1.45 | 2000 | .65 | .80 | No | |
| 011303 | Room | Halon 2402 | 4.0 | 3100 | .43 | 1.07 | 1300 | .57 | .50 | No | |
| 011304 | Room | Halon 2402 | 4.0 | 2700 | .50 | 1.37 | 1800 | .82 | .55 | No | |
| 011602 | Room | Halon 2402 | 4.0 | 2900 | .43 | 1.37 | 1700 | .67 | .70 | Yes | |
| 011603 | Room | Halon 2402 | 4.0 | 2000 | .89 | 1.42 | 1800 | .92 | .50 | Yes | |
| 011604 | Room | Halon 2402 | 3.5 | 3000 | .42 | 1.22 | 1700 | .72 | .50 | Yes | |

## TABLE IV (cont.)

## TEST SUMMARY

## PROJECT 4599 - AF-33615-68-C-1121

| Test No. | Temp. | Agent & Qty (lb) | PROPELLANT CHAMBER | | | AGENT CHAMBER | | | Fire Exting. | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Peak Press (psi) | Time to Peak (sec) | Total Run Time (sec) | Peak Press (psi) | Time to Peak (sec) | Decay Time (sec) | | |
| 012103 | Room | Halon 2402 4.0 | 1700 | -- | -- | 1700 | -- | -- | -- | No Discharge |
| 012704 | Room | Halon 2402 4.0 | 1900 | -- | -- | 1800 | -- | -- | -- | No Discharge |
| 012705 | Room | Halon 2402 3.0 | 2700 | .45 | 1.37 | 1900 | .67 | .70 | No | |
| 012706 | Room | Halon 2402 3.5 | 3100 | .45 | 1.32 | 2000 | .67 | .65 | No | |
| 012707 | Room | Halon 2402 4.0 | 2900 | .42 | 1.27 | 1600 | .62 | .65 | No | |
| 020403 | Room | Halon 2402 4.0 | 2900 | .55 | 1.48 | 1100 | .73 | .75 | No | Invalid |
| 020602 | Room | Halon 2402 4.0 | 3000 | .45 | -- | 1000 | -- | -- | -- | No Discharge |
| 020603 | Room | Halon 2402 4.0 | 3300 | .45 | 1.60 | 600 | .60 | 1.00 | No | Fire appeared out but returned |
| 020604 | Room | Halon 2402 4.0 | 3300 | .50 | 1.60 | 600 | .65 | .95 | No | |
| 020605 | Room | Halon 2402 4.0 | 3400 | .58 | 1.70 | 900 | .73 | .97 | No | |
| 021302 | Room | Halon 2402 4.0 | 2900 | .80 | -- | 1100 | 1.00 | -- | -- | No Discharge |
| 021303 | Room | Halon 2402 4.0 | 2600 | .70 | 2.00 | 1500 | 1.28 | .72 | Yes | |
| 021304 | Room | Halon 2402 4.0 | 3000 | .45 | 1.60 | 1700 | .72 | .88 | Yes | |
| 022504 | Room | Halon 2402 4.0 | 3100 | .65 | 1.70 | 1300 | .80 | .90 | No | |
| 022506 | Room | Halon 2402 4.0 | 3000 | -- | -- | 1550 | -- | .70 | Yes | |
| 022507 | Room | Halon 2402 3.5 | 3000 | .50 | 1.60 | 1700 | .77 | .83 | No | |
| 022508 | Room | Halon 2402 3.5 | 3100 | .48 | 1.65 | 1900 | .72 | .93 | No | |

## TABLE IV (cont.)

## TEST SUMMARY

## PROJECT 4599 - AF-33615-68-C-1121

| Test No. | Temp. | Agent & Qty | (lb) | PROPELLANT CHAMBER | | | AGENT CHAMBER | | | Fire Exting. | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Peak Press (psi) | Time to Peak (sec) | Total Run Time (sec) | Peak Press (psi) | Time to Peak (sec) | Decay Time (sec) | | |
| 030503 | Room | Halon 2402 | 4.0 | 3000 | -- | 2.10 | 1600 | -- | .90 | Yes | |
| 030504 | Room | Halon 2402 | 4.0 | 3500 | .43 | 1.50 | 1800 | .57 | .93 | No | |
| 030505 | Room | Halon 2402 | 3.5 | 3200 | .43 | 1.50 | 1900 | .61 | .89 | No | |
| 031202 | -65°F | Halon 2402 | 4.0 | 3100 | .80 | -- | 1500 | -- | -- | -- | |
| 031203 | -65°F | Halon 2402 | 4.0 | 3100 | .55 | -- | 1300 | -- | -- | -- | |
| 031204 | -65°F | Halon 2402 | 3.5 | 2900 | .53 | 1.70 | 1800 | .75 | .95 | Yes | |
| 031205 | -65°F | Halon 2402 | 3.5 | 3000 | .75 | 1.50 | 1800 | .90 | .60 | No | |
| 031302 | -65°F | Halon 2402 | 4.0 | 3100 | .45 | 1.65 | 1800 | .65 | 1.00 | Yes | |
| 031303 | -65°F | Halon 2402 | 4.0 | 3200 | .44 | 1.60 | 1200 | .60 | 1.00 | No | |
| 031304 | -65°F | Halon 2402 | 3.5 | 3100 | .45 | 1.70 | 1800 | .65 | 1.05 | No | |
| 031902 | -65°F | Halon 2402 | 4.0 | 3100 | .55 | 1.80 | 2000 | .83 | .97 | No | Fire not standard |
| 031903 | 500°F | Halon 2402 | 3.5 | 3500 | .30 | .85 | -- | -- | -- | No | Fire not standard |
| 031904 | Room | Halon 2402 | 4.0 | 3100 | .30 | 1.40 | 2000 | .52 | .98 | No | Fire not standard |
| 032502 | 500°F | Halon 2402 | 3.5 | 3600 | .35 | .90 | -- | -- | -- | No | |
| 032503 | 500°F | Halon 2402 | 3.5 | 3900 | .30 | .85 | -- | -- | -- | Yes | |
| 032504 | .65°F | Halon 2402 | 4.0 | 3100 | .42 | -- | 3200 | .65 | -- | -- | |
| 032505 | 500°F | Halon 2402 | 3.5 | 3700 | .30 | 1.00 | -- | -- | -- | Yes | |

Testing continued with various distribution systems until run 020605. After an analysis of the data and a discussion with NAFEC personnel on their observations of the relative effectiveness of the two extinguishing systems, it was decided that the distribution system used on January 16, 1969 represented by run 011602 to run 011604 was the most suitable for further ambient and environmental testing. This distribution system was maintained for most of the runs performed after 020605.

The testing conducted on February 4, 1969, represented by run 020403, was invalid since neither the nitrogen nor the pyrotechnic units could extinguish the fire with four pounds of agent due to an obstruction in the discharge nozzle.

A typical ambient temperature test reaches a peak pressure of approximately 2700 psi in the propellant chamber, 0.50 seconds after firing. A peak pressure of approximately 1700 to 2200 psi is reached in the agent chamber in about 0.90 seconds after ignition. The complete agent discharge cycle is accomplished in about 1.7 seconds with an average agent discharge rate of 0.80 seconds. The pressure-time data for run 120404, which is typical of the tests performed, is shown in Figure 8.

The average discharge rate of 0.80 seconds conforms to the 0.50 to 1.0 second limits specified in MIL-E-22285 for high rate fire extinguishing discharge systems. In the previous programs the effectiveness of the subscale system was very dependent on the discharge rate. Fires were only extinguished when the rate was between 0.60 to 0.80 seconds, however, with the full scale system fires were extinguished with rates as low as 0.50 seconds and as high as 0.95 seconds.

The only functional problem encountered during the ambient testing concerned a burn-through of the propellant chamber wall. This first occurred during run 012103. The carbon screen and orifice design routed the hot gas around the outside diameter of the screen slightly eroding the wall with each firing.

A burn-through occurred during run 012103. This was the fifth firing performed with unit #5. All of the remaining units were inspected and all showed some signs of erosion. It was decided to reduce the size of the carbon screen to increase the clearance between the screen and the chamber wall. This would decrease the velocity of the hot gas in this area and hopefully minimize the erosion.

Unit #2 which showed the most signs of wear was then fired (run 012704) using the smaller screen. A burn-through of the chamber wall occurred. This was also the fifth time unit #2 had been fired.

A one inch long carbon sleeve was then located in the erosion area to shield the wall from further hot gas impingement. The sleeve butted against the orifice and was connected to it with selectron. The flow around the screen now passed between O.D.

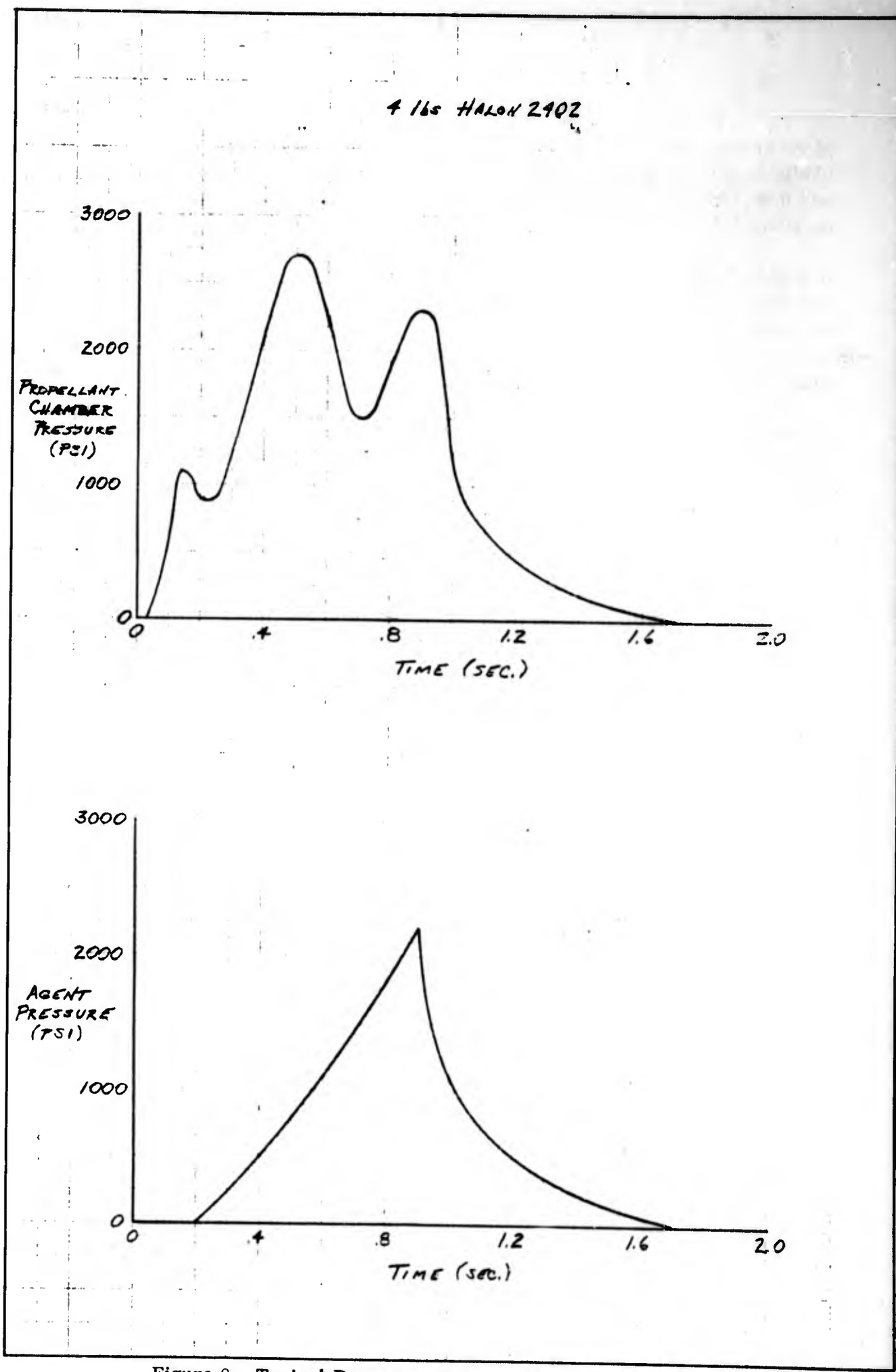


Figure 8. Typical Pressures Generated During Tests

of the screen and the I.D. of the sleeve. This configuration was used from runs 012705 to 020605 and performed satisfactorily. Failure to discharge in run 020602 was due to a leak caused by a loose outlet fitting and not to a burn-through of the chamber wall.

Run 020901 (Table III) was conducted in-house with a new propellant chamber and a full length carbon sleeve, 4 inches long. There was no sign of erosion and this design was incorporated in all of the NAFEC tests beginning with run 021302. Erosion of this chamber wall above the short (1") sleeve had not occurred but the longer sleeve was substituted as a precautionary measure.

In the very first run using the longer sleeve a burn-through occurred in one of the original chambers (S/N 3). This was the eighth test with this chamber and its failure was attributable more to its past firings than its last run. Throughout the remainder of the test program the last of the original chambers held up (13 runs total) and the new chambers exhibited minimal erosion.

Success with the pyrotechnic extinguishing units and $CF_2Br$-$CF_2Br$ (Halon 2402) on the "standard" fire was satisfactory. A total of thirty eight runs were conducted with various quantities of agent at room temperature. Thirteen of these were performed with a distribution system that appeared to be "standard", in that it did not obviously favor one extinguishing system over another. The pyrotechnic system with 4 pounds of agent extinguished the "standard" fire in six out of eight attempts using the "standard" distribution system. The pyrotechnic unit also extinguished the fire with 3 1/2 pounds of agent in one out of four attempts, while in one run the agent did not discharge.

A direct comparison of the effectiveness of the different extinguishing systems is difficult due to the instability of the "standard" fire conditions and the "standard" distribution system. The "standard" fire was very dependent on weather conditions, particularly wind direction which of course varied throughout the program as well as on any given day. There were periods of a week or more during the test program in which as little as 2.5 pounds of agent could extinguish the fire while on other occasions 4 pounds of agent didn't come close.

Due to handicaps such as these an analysis of the data is subject to some conjecture. It appears that the performance of the nitrogen and pyrotechnic systems with their respective agents (Halon 1301 vs Halon 2403) on an agent weight basis is similar when used with a distribution system that is suited to their particular requirements. The nitrogen system is much more flexible as it is effective with a variety of distribution systems while the pyrotechnic system would require a system tailored to its needs.

It is apparent from Figure 9, however, that on a system weight effectiveness basis the pyro unit whether spherical or cylindrical is definitely superior to a conventional system. The decrease in system weight for the pyrotechnic unit is due to the elimination of nitrogen and the lack of constant pressure in the container. This constant pressure results in a higher stressed container necessitating thicker walls.

The weights presented in Figure 9 are for containers operating between -65°F to 200°F. The weights of the pyrotechnic units would remain almost the same if the temperature limit was raised above 200°F while the weight of the $N_2/CF_3Br$ systems would have to increase significantly to meet the large increase in vapor pressure that occurs at elevated temperatures.

The pyrotechnic unit possesses additional advantages as regards installation, recharge and gunfire characteristics. Installation is easier since the container envelope is smaller and the unit may be mounted in any attitude. Recharge equipment is reduced to a minimum since a nitrogen source is not required and the agent used is a liquid rather than a gas. Gunfire isn't a problem since the unit isn't pressurized other than during the discharge cycle.

Because there is also less variation in discharge time over the temperature range the pyrotechnic unit has superior performance compared to the $CF_3Br$/nitrogen system at the environmental extremes of -65°F and 500°F. The $CF_3Br$ unit below -40°F is not a high rate discharge system and at 500°F its high vapor pressure prohibits its use in a standard light weight container. During this test program the $CF_3Br$/nitrogen system was not tested at the -65°F and 500°F conditions because of these characteristics, therefore, the performance of the pyrotechnic units at the temperature extremes can only be compared with its own performance at room temperature.

b. Cold Tests (-65°F)

Only one operational problem was encountered with the pyrotechnic extinguisher at -65°F. In two tests (Runs 031202, 031203) the agent outlet disc did not rupture. At this temperature the nominal bursting pressure of the disc increases by about 200 - 300 psi but sufficient agent pressure to rupture the disc was not produced indicating a need for additional propellant. The grain used prior to and during these tests weighed 105 grams. An additional 15 grams of grain was provided beginning with run 031204. This added grain weight proved to be sufficient to burst the outlet discs in subsequent testing. The lack of discharge in run 032504 was not attributable to insufficient grain as evidenced by the 3200 psi peak pressure reached in the agent chamber. Two discs had erroneously been inserted instead of one and the required burst pressure for this combination was approximately 4000 psi.

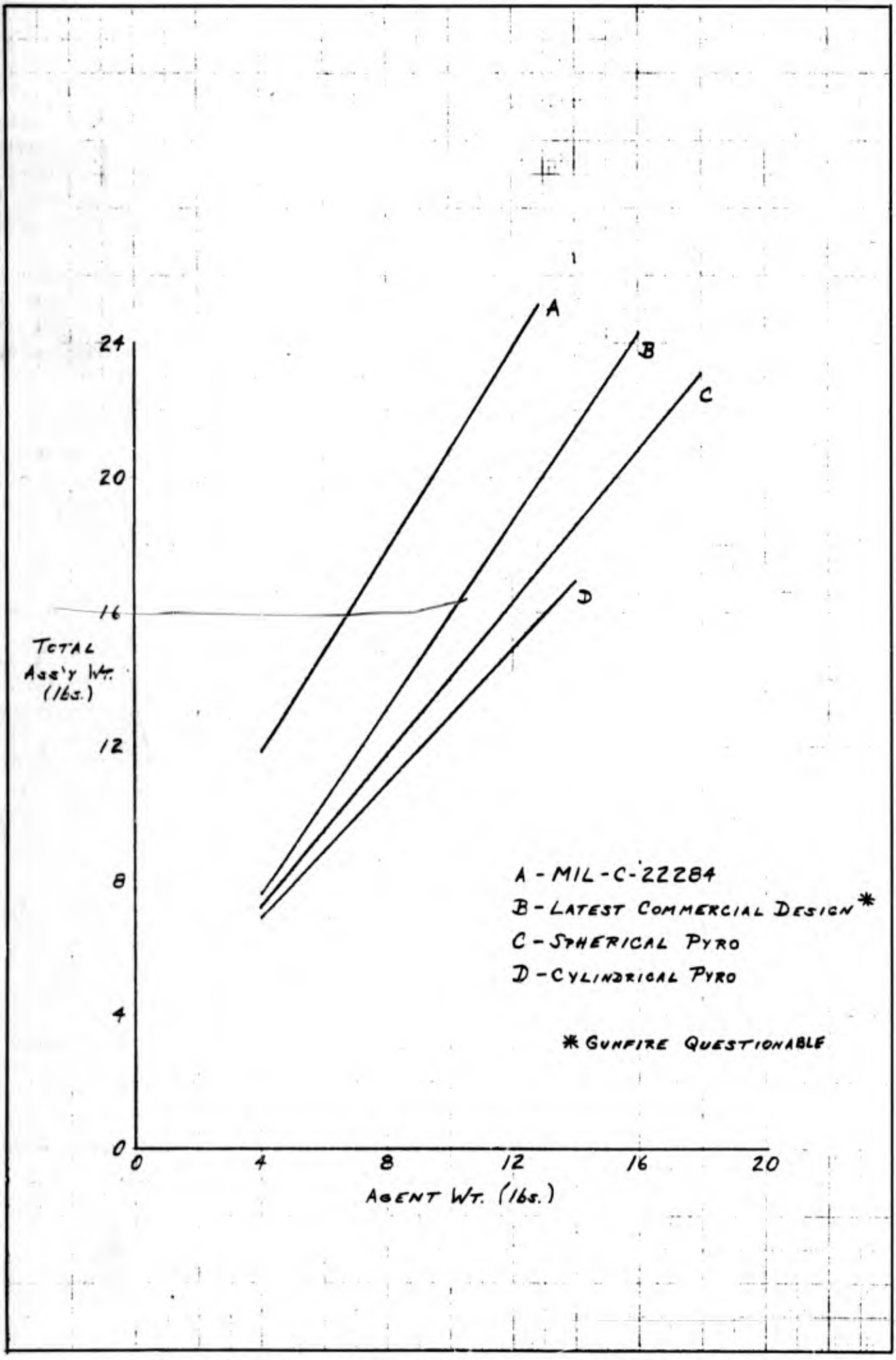


**Figure 9. Total Assembly Weight vs Agent Weight**

Performance of the pyrotechnic extinguisher after 24 hour soak at -65°F was similar to that experienced at room temperature. The test fire appeared to be extinguished in all the unsuccessful runs but some flame must have remained in the aft fan section as the fire returned after the smoke and agent vapor cleared. This characteristic was common in most of the unsuccessful runs at all temperatures. It was especially prevalent in the -65°F tests as the fire appeared to be extinguished for about 5 seconds before it returned.

The pyrotechnic unit extinguished the standard fire in one out of three runs with 3 1/2 pounds of agent and in one out of two runs using 4 pounds of agent. Runs 03190 to 031904 were invalid since "standard" fire conditions were not maintained.

In run 031303 where 4 pounds of agent did not extinguish the fire the outlet disc in the agent chamber burst prematurely (1200 psi). Due to this there was a lack of sufficient heat applied to the agent. The average agent temperature reached was only 100°F which is below the agent boiling point (117.5°F) indicating that a significant quantity of agent reached the test fire in a liquid state. Figure 10 shows the average temperature of the agent reaching the test fire.

c. Hot Tests (500°F)

Operational problems with the pyrotechnic units were not encountered at elevated temperatures. The performance after 24 hour soak at 400°F to 500°F was superior to that experienced at room temperature as expected. At the elevated temperatures the Halon 2402 agent always reaches the test fire in an active completely gaseous state which increases its efficiency.

In general, the hot test firings also possessed an extremely rapid discharge, about 0.5 seconds, from peak (burst of agent outlet disc) to complete expulsion. This rapid discharge did not however, handicap performance as was the case with the subscale units.

It should also be considered in comparing the performance of the pyrotechnic unit to the $CF_3Br/N_2$ system that the nitrogen aids fire extinguishment. This weight of nitrogen represents a significant percentage increase in agent loading. Another consideration, as it effects a direct comparison of the results, is that the Halon 2402 ($CF_2Br-CF_2Br$) is known to be a slightly less effective extinguishant compared to Halon 1301 ($CF_3Br$) when expelled with a cold gas (nitrogen) pressurization system.

d. Statham Analyzer Tests

A series of tests were conducted in order to assess the effectiveness of current gas analyzer fire extinguisher system evaluation tests on a pyrotechnically discharged system. The same NAFEC test nacelle used in the fire tests was instrumented with pick up probes and sampled by the Statham agent concentration recorder.

A quantity of four pounds of agent was discharged under the same conditions of airflow used in the fire tests.

The gas sample was dra. n through heated prefilters as previously developed by Kidde for use in the sampling of pyrotechnic discharges.

No marked difference in results was noted beyond that which might be expected due to the normal difference in discharge characteristics.

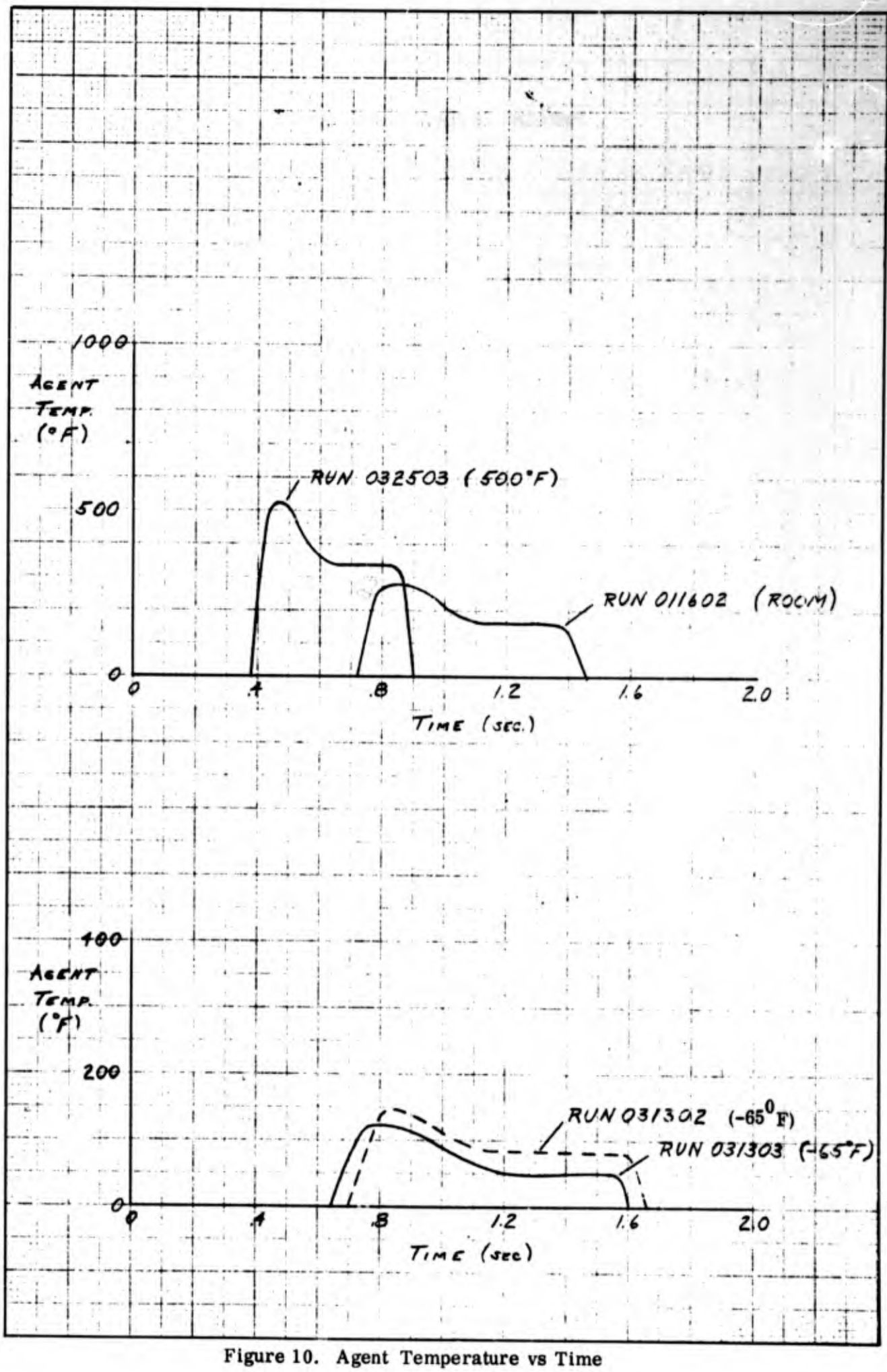


Figure 10. Agent Temperature vs Time

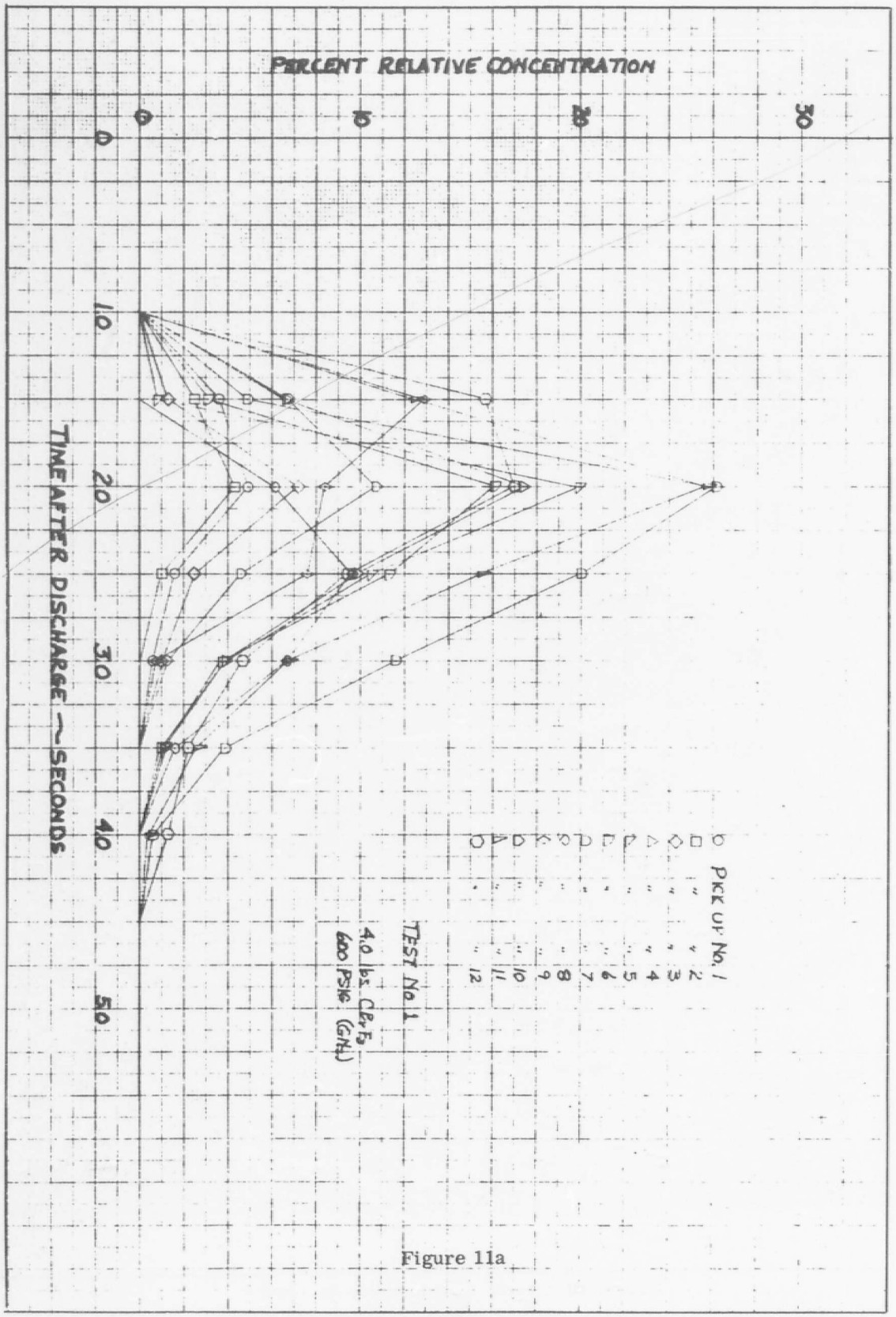
PERCENT RELATIVE CONCENTRATION
0
10
20
30
TIME AFTER DISCHARGE ~ SECONDS
0
10
20
30
40
50
PICK UP No. 1
" " 2
" " 3
" " 4
" " 5
" " 6
" " 7
" " 8
" " 9
" " 10
" " 11
" " 12
TEST No 1
4.0 lbs $CBrF_3$
600 PSIG ($GN_2$)

Figure 11a

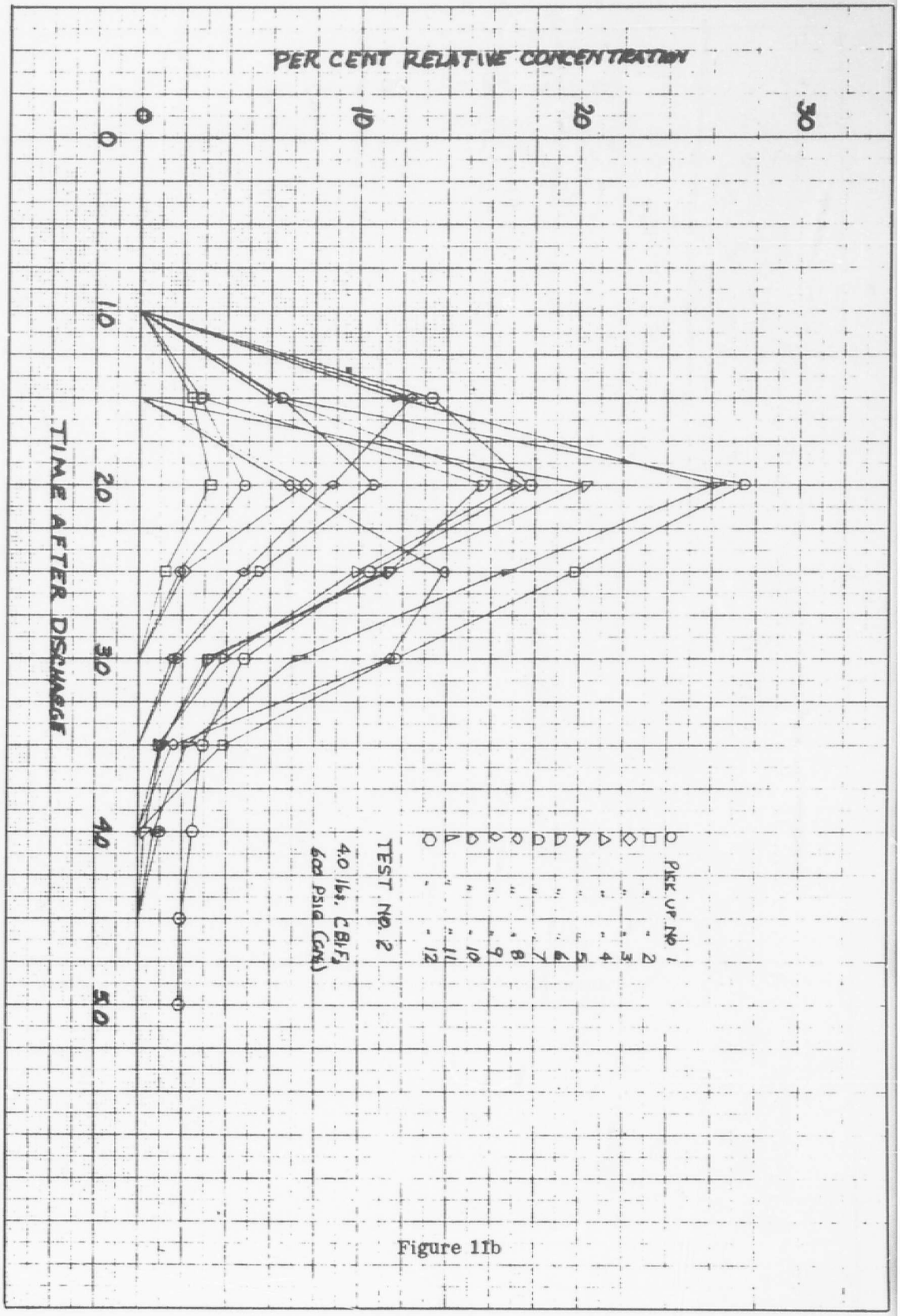
PER CENT RELATIVE CONCENTRATION
0
10
20
30
TIME AFTER DISCHARGE
0
10
20
30
40
50
PICK UP NO 1
" " - 2
" " - 3
" " - 4
" " - 5
" " - 6
" " - 7
" " - 8
" " - 9
" " - 10
" " - 11
" " - 12
TEST NO 2
4.0 lbs. CBrF3
600 psig (GN2)

Figure 11b

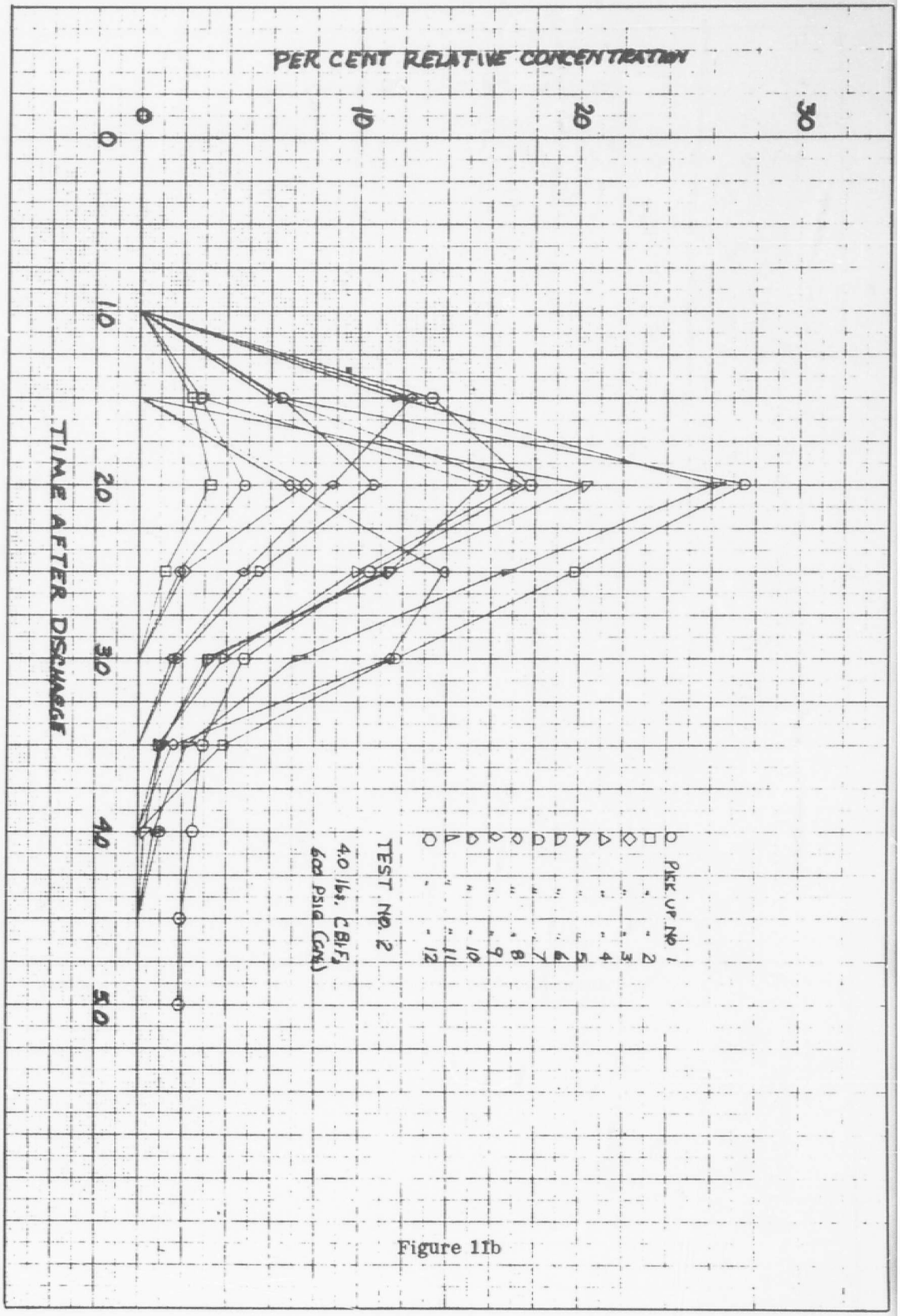
PER CENT RELATIVE CONCENTRATION
0
10
20
30
TIME AFTER DISCHARGE
0
10
20
30
40
50
PICK UP NO 1
" " - 2
" " - 3
" " - 4
" " - 5
" " - 6
" " - 7
" " - 8
" " - 9
" " - 10
" " - 11
" " - 12
TEST NO 2
4.0 lbs. CBrF3
600 psig (GN2)

Figure 11b

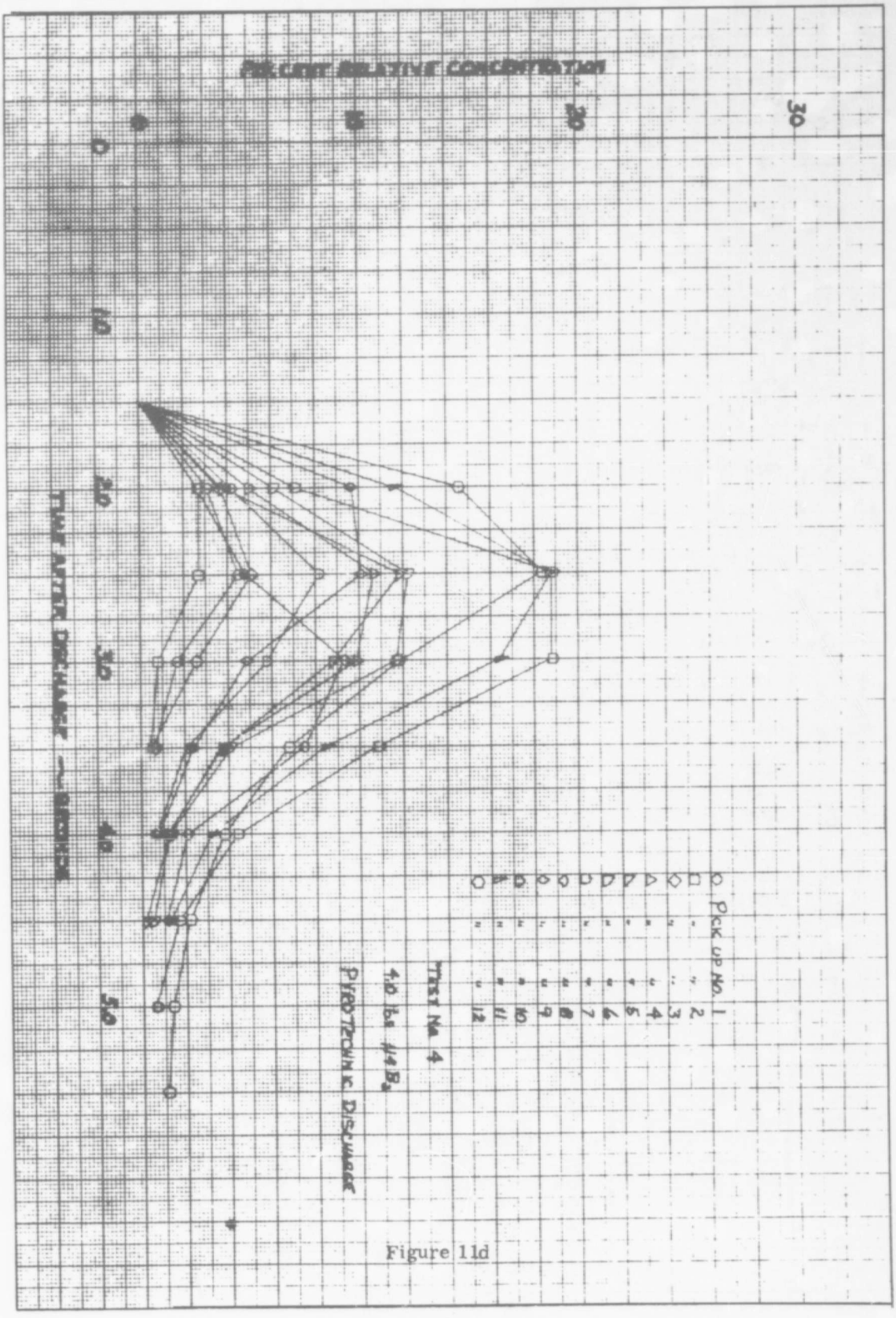
PER CENT RELATIVE CONCENTRATION
0
10
20
30
TIME AFTER DISCHARGE — SECONDS
0
1.0
2.0
3.0
4.0
5.0
PICK UP NO. 1
" " 2
" " 3
" " 4
" " 5
" " 6
" " 7
" " 8
" " 9
" " 10
" " 11
" " 12
TEST No 4
4.0 lbs 1/4 B2
PYROTECHNIC DISCHARGE

Figure 11d

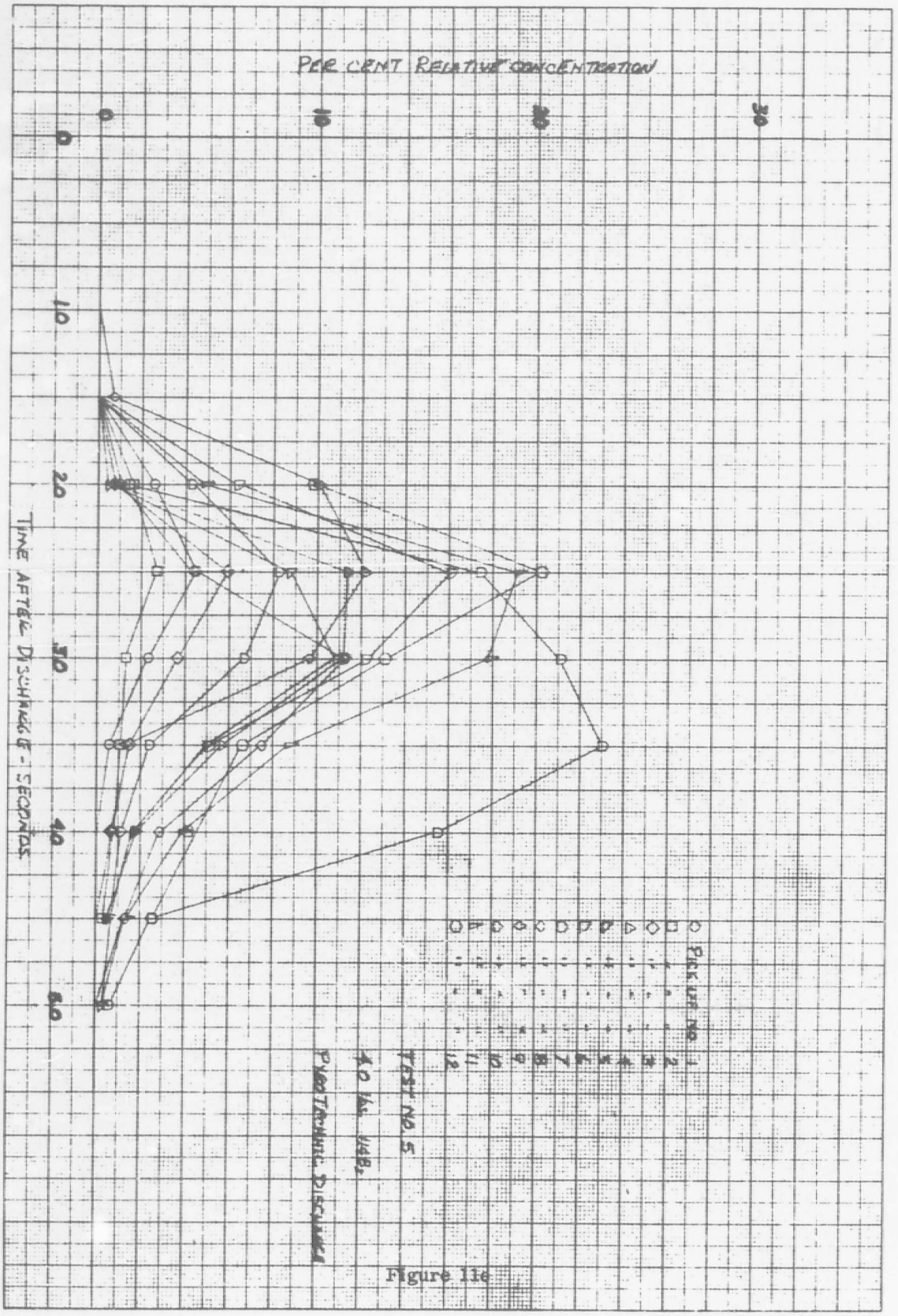
PER CENT RELATIVE CONCENTRATION
0
10
20
30
0
10
20
30
40
50
TIME AFTER DISCHARGE - SECONDS
PICKUP NO. 1
2
3
4
5
6
7
8
9
10
11
12
TEST NO. 5
40 lbs. MgBr2
PHOTOTUBE DISCHARGE

Figure 11c

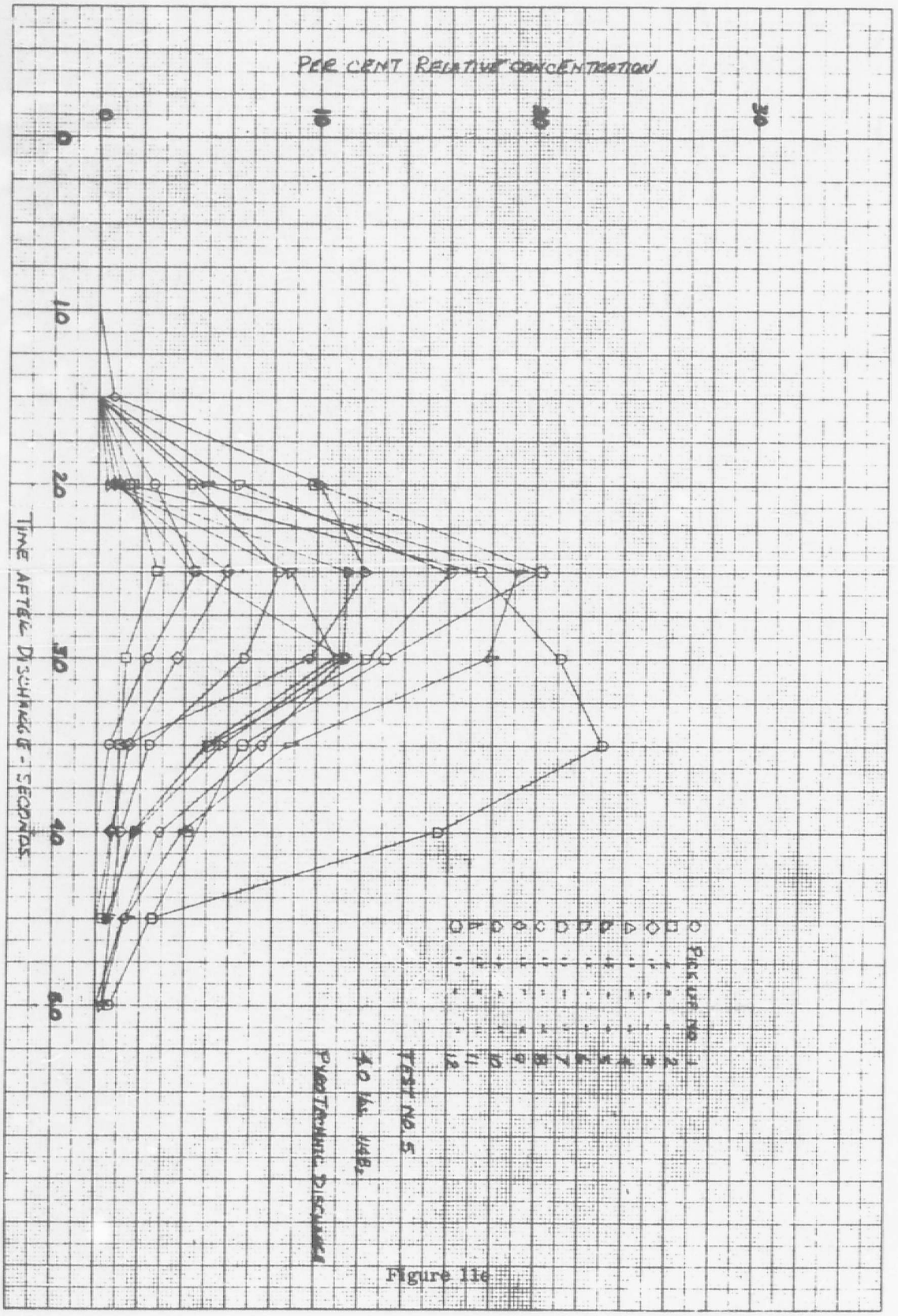
PER CENT RELATIVE CONCENTRATION
0
10
20
30
0
10
20
30
40
50
TIME AFTER DISCHARGE - SECONDS
PICKUP NO. 1
2
3
4
5
6
7
8
9
10
11
12
TEST NO. 5
40 lbs. MgBr2
PHOTOTUBE DISCHARGE

Figure 11c

## SECTION IV

## RESULTS AND CONCLUSIONS

The conduction of this program and the results and the analyses of the experimental data, indicate that the pyrotechnic fire extinguishing system is applicable to the flight safety requirements of advanced aircraft whether operating in a conventional environment or at elevated temperatures. The most significant results are discussed below:

1. The pyrotechnic extinguishing system met the requirements of Specification MIL-E-22285 for high rate discharge and has been developed into a full scale prototype system.

2. The pyrotechnic unit has reliably operated and extinguished fires created in the simulated nacelle over a -65°F to 500°F temperature range.

3. The performance of the pyrotechnic system at room temperature exceeds that of the $CF_3Br/N_2$ system on a system weight basis while the latter system is not adaptable to operation at elevated temperatures.

4. The extinguishing agent, Halon 2402, is compatible with materials such as titanium, associated with advanced aircraft, under long term storage at 500°F.

5. Successful firings were also performed with the solid grain self-pressurizing system after 400 hours at 450°F.

6. On the basis of the testing performed employing the gas analyzer, it is concluded that no difficulty should be encountered in performing system effectiveness tests of pyrotechnically discharged systems.

It is recommended that an extensive Statham Analyzer program be conducted to firmly establish the performance capabilities of this technique and to qualify the system.

# APPENDIX I

REPORT TO

WALTER KIDDE & COMPANY, INC.

ON

HIGH TEMPERATURE PYROTECHNIC SUB-SYSTEM

PART NUMBER 216302

January 7, 1969

ET-336

Submitted by Aerospace Research Corporation, Roanoke, Virginia as part of performance against Kidde Purchase Order No.
under Contract AF 33615-68-C-1121

REPORT TO

WALTER KIDDE AND COMPANY

ON

# HIGH TEMPERATURE PYROTECHNIC SUBSYSTEM

PHASE II

BUDGET PROGRAM SEQUENCE NUMBER 6(63-60750762405214)

Joseph T. Hamrick and Leslie C. Rose

January 7, 1969

Aerospace Research Corporation

Roanoke, Virginia

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REPORT TO WALTER KIDDE & COMPANY, INC.

ON HIGH TEMPERATURE PYROTECHNIC SUBSYSTEM - PHASE II

## SECTION I

## INTRODUCTION

In the Phase 1 program a small scale pyrotechnic subsystem was developed around formula AeReCo 706D propellant. It was demonstrated that this system could tolerate temperatures ranging from -65°F to 500°F and function satisfactorily at any temperature within that range. The purpose of Phase II of the program was to further develop the system with regard to size, quality control, and reliability and to establish a level of confidence in its ability to fulfill the requirements of the application. Two systems, both of which were approximately five times the size of the system developed in Phase I, were designed and experimentally evaluated. One of these systems employed a one and one quarter inch diameter propellant grain which in order to meet the heat and gas volume requirements resulted in a propellant charge approximately six inches long. A second system employed a grain one and one half inches in diameter with a charge approximately four inches long.

In addition to the necessity to further develop fabrication and quality control techniques, there was the requirement to provide a balance between the igniter charge, sustainer, and propellant grains. Achievement of a functional system over the temperature range required experimental evaluation of each system with regard to rupture disc strength exhaust nozzle area, and chamber ullage as well as weight distribution of the pyrotechnic components. It is the purpose of this report to present the

design concepts, fabrication techniques, experimental results, an evaluation of the results, and recommendations for further development. These are included in the subsequent pages.

Thermochemical calculations, environmental resistance, ballistic performance, and general capabilities of AeReCo 706D propellant, AeReCo 791 sustainer and AeReCo 790 igniter powder were presented in the Phase I report and will not be repeated herein. Propellant grains with integral sustainer were evaluated by the Bureau of Explosives as to shipping classification. When packaged in accordance with paragraph 173.154(a) (8) or (a) (12) of Department of Transportation regulations, the propellant with sustainer is classed as a flammable solid. The Bureau of Explosives report is included herein as Appendix I.

## SECTION II

## DESIGN CONSIDERATIONS

There are two aspects to the design approach. The first is concerned with the pyrotechnic components which may remain essentially as initially developed when used in the final application and the second with the gas generator hardware which for development applications is quite heavy and will not remain essentially as initially developed except possibly for the internal configuration. The factors which entered into the overall design and the design of the components are discussed in the following paragraphs.

### Preliminary Grain Design

The grain used in Phase I contained seven perforations, one in the center with six symmetrically spaced around it. In arriving at the number and arrangement of perforations, primary consideration was given to web thickness which determines the burn time for the grain at any given pressure. The perforation must be of adequate diameter to conduct the generated gases along at least half its length without excessively eroding the surface and also large enough to easily admit igniter gases. On the other hand, perforations that are too large may provide excessive ullage in the generator which can give rise to ignition problems. Grain diameters of 1 1/4 inches and 1 1/2 inches were selected with the approval of Walter Kidde and Company, and it was found that a seven perforation arrangement, like that used in Phase I, would be satisfactory if the resulting grain lengths could be tolerated. A six inch length for 1 1/4 inch diameter and a four inch length for 1 1/2 inch diameter were necessary in order to meet the grain weight requirement. After considering several factors, it was decided that all grains would be made in approximately 2 to 2½ inch lengths. Among the factors considered were the difficulties in perforating the solid

grains in lengths exceeding two inches and the fact that most U. S. Army cannon propellants use a length to diameter ratio of approximately two and one half. Also, in pressing grains of high length to diameter ratio there are problems associated with consolidation and with extraction from the die after pressing. Formation of the perforations can be accomplished either by use of multiple mandrels placed in the die or by drilling after pressing the grain. With either method the problems are made more severe with increasing grain length. For example, with a 1 1/4 inch diameter grain 6 inches in length it is probable that the perforations could be formed by incorporating mandrels in the die but this is generally beyond the state of the art for pressed grains as most perforated grains are formed by extrusion. One of the factors that had to be considered, which is not normally encountered with cannon propellants, is stacking of the grains end to end in the generator. It was found, however, that the perforation diameters which would be required to remain within the specified burning time would be large enough to preclude blockage of the flow path within the grain due to the web of one grain abutting the perforation of another. Also, regardless of how firmly the grain is held initially, the rapid burning of the sustainer cap on the lead grain shortens it and allows room for the grains to shift and provide openings between them. As with the propellant grains in Phase I, it is necessary to provide standoffs on the grains to keep them centered in the generator. For the program performed at Aerospace Research Corporation nichrome wires were glued at 90° intervals along the length of each grain segment.

Igniter System Design

The igniter system in the Phase I design consisted of an electrically

ignited powder charge and a pressed sustainer charge. It was proposed to use the same basic system in the Phase II design. However, it was anticipated that if the sustainer charge was increased in direct proportion to the basic propellant charge the difficulties encountered with high temperature gases might be significantly increased because of the momentarily higher sustained temperatures that would be generated. The use of a higher pressure rupture disc than was used in Phase I was considered and more detailed attention was given to the sustainer cap design. For example, the depth of penetration of the grain perforation into the sustainer cap attached to the end of the grain affects the quantity of hot gases provided by the sustainer within the perforations. This can be best explained by noting that the sustainer is pressed integral with a solid grain before the grain is drilled from the uncapped end. The drilling is then performed using a standard $120^{\circ}$ drill point. With drilling of the perforations completely through the propellant grain a conical surface is provided inside the sustainer material. This surface changes with the depth of the drilling into the sustainer and thus close control must be exercised.

Gas Generator Design

The gas generator for this phase of the work is quite similar to that of the first phase. As with the generator in the first phase much heavier walls were used in the generator than would be used in the final generator design because of the experimental nature of the program. As a result the heat transfer from the generated gases for the sustainer or the grain would be different from that experienced in the final generator design and this will have to be taken into account in the design for which the thinner walls would tend to heat up faster but for which there is a cooling effect from

the surrounding liquid. The difference is in the two cooling media (heavier generator walls versus liquid) were not evaluated. It was expected in these designs that an area of primary complication would be the carbon screen because of the larger quantity of propellant with only a small increase in the diameter of the carbon filter. Two propellant grains were designed and submitted for approval to Walter Kidde & Company. They are shown in figures 1 and 2 installed in the gas generators used in evaluating them. All of the features incorporated into the generator used in Phase I were used in the generators of Phase II.

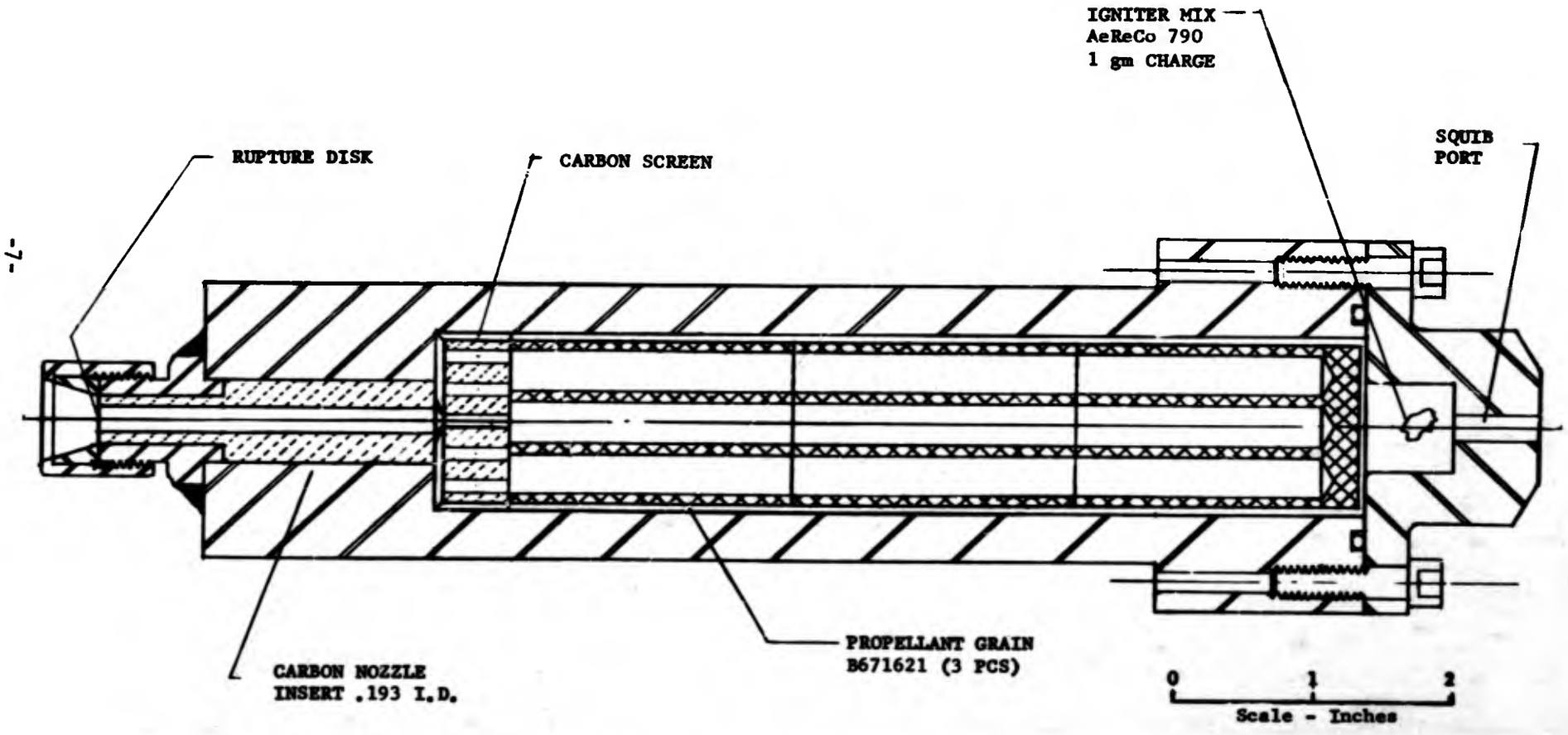


Figure 1 - Heavy weight gas generator for pyrotechnic subsystem using 1 1/4 inch diameter grain-
Bore Diameter 1.375 inches

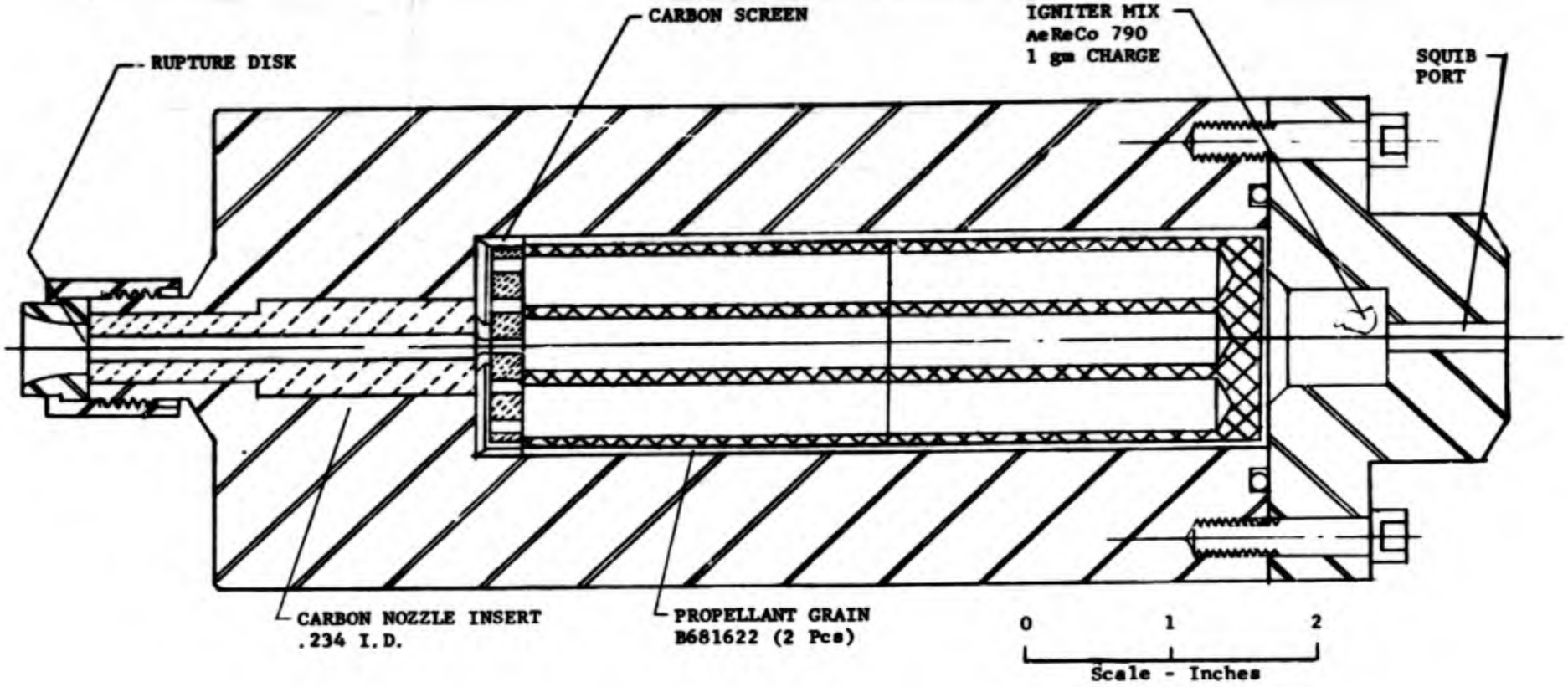


Figure 2 - Heavy weight gas generator for pyrotechnic subsystem using 1.5 inch diameter grain-
Bore Diameter 1.625 Inches

## SECTION III

## FABRICATION

The term fabrication applies to preparation of the propellant grains as well as the gas generator hardware. Fabrication of the gas generator is considered first.

### Gas Generator Fabrication

Both gas generators were fabricated from 304 stainless steel. Silicone rubber O-Rings were used to provide sealing at the generator cap. All carbon parts were made from ordinary electrode carbon. Both the holes and the passage ways in the screen and the nozzle diameter in the carbon nozzle section were initially estimated from the dimensions of the gas generator used in Phase I. The rupture discs were made from brass shim stock. The most critical part of the design involved a balance of total passage area through the carbon screen as related to the diameter of the nozzle. The nature of the residue from the system is such that closure of the passages in the screen results from accumulation of slag and small particles. Test results indicate that the extent of exposed screen surface area is important. It is assumed, although not substantiated, that a similar build-up would occur on the nozzle if the carbon screen was not there. Thus the screen serves a double purpose of preventing build-up on the nozzle surface as well as screening out particles large enough to plug the nozzle. Because of the build-up and particle clogging of the screen the sizing of the passages on the screen had to be determined experimentally. Detailed views of the carbon screens are shown in figure 3.

The rupture disc burst pressure best suited to the Phase I generator would not necessarily be best for Phase II, because of the reluctance to scale up the igniter as previously discussed in the section on preliminary

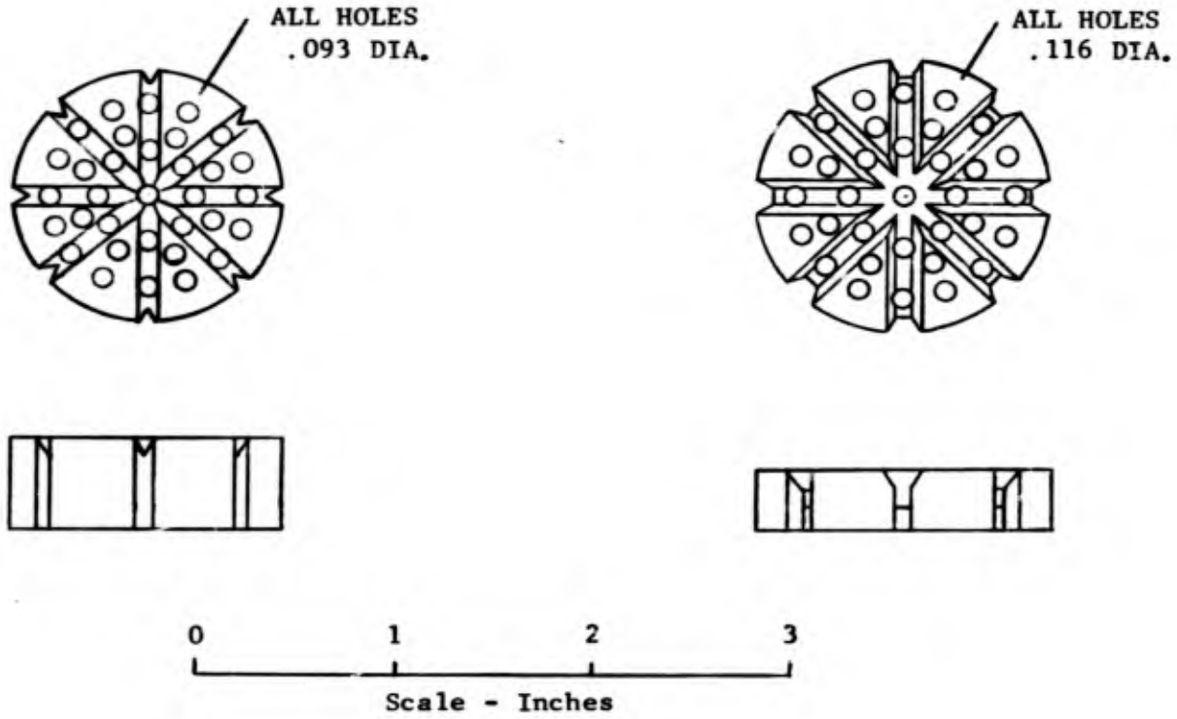


Figure 3 - Views of carbon screens for 1.25 inch and 1.50 inch diameter grains, pyrotechnic subsystems, Phase II

design. It was expected with the change in overall configuration that it would be necessary to utilize a higher rupture pressure.

Propellant Grain Fabrication

For this application, the grains are pressed in solid cylinders, cured at 500°F, and drilled. The shavings from the drilling are mixed with new material and re-pressed. This is a procedure that effects a significant economy in the absence of tooling which would allow processing the grains with perforations in a single operation. The economy thus effected reflects not only the cost of ingredients, but also the processing time for the mixture. A study of the tooling problems that may be encountered has not been made. The main difficulties encountered with present methods were extraction of the 1.5 inch pressed grain from the die and drilling. Both the one inch diameter die and the 1.25 inch die were made from austenitic stainless steel. The 1.5 inch die was made from carbon steel and it was difficult to obtain as smooth a cylinder wall with the carbon steel as was obtainable with the stainless steel. This resulted in uneven emergence of the grain from the die with accompanying fissuring on the side that emerged first. Grains on which the fissuring was detected were scrapped and no significant departure in performance was experienced due to any that may have gone undetected. The scrap rate was decreased greatly with die use. Drilling, especially with the 1.5 inch grain, resulted in cold working with resultant softening of the propellant adjacent to the perforations. This did not appear to affect performance.

The grains were cured for two hours at 500°F. A larger cure period of four hours was evaluated with no apparent departure from results obtained with the two hour cure.

The AeReCo 791 cap on the 1 1/2 inch diameter grain weighs 10 grams as compared to 8 grams for the 1 1/4 inch diameter grain. The one inch grain used in Phase I contained 5 grams.

## SECTION IV

## EXPERIMENTAL RESULTS

The objective of the experimental evaluation was to characterize each propellant system over a range of temperatures from -65°F to 500°F. Initially, firings were made at ambient to determine approximately the correct nozzle diameter. Firings were then made at -65°F followed by firings at 500°F. Adjustments were made in nozzle diameter and screen hole sizes as required to keep the outlet pressure below 4000 psi at 500°F and still effect a firing at -65°F.

### Test Setup and Instrumentation

The generators were fired remotely in the horizontal position. Chamber pressure was recorded by means of a temperature compensated strain gage type transducer and a direct writing oscillograph. The mirror galvanometer used in this application had a flat frequency response of 120 cycles per second. The system was calibrated periodically by means of a dead weight tester. For firings at -65°F the assembled gas generator system was conditioned for a minimum of six hours. For firings at 500°F the conditioning time was a minimum of four hours. The transfer interval from time of removal from the conditioning chamber to firing was recorded. Initial tests were made with 1.25 inch diameter grains in the generator as shown in Figure 1. These were followed by tests with 1.5 inch diameter grains in the generator as shown in Figure 2.

### Test Results With 1.25 inch Diameter Grain

Fifteen tests were made with the 1.25 inch diameter grain arranged as shown in Figure 1. As previously indicated it was considered desirable from standpoint of temperature to maintain the one-fourth inch thickness

for the sustainer cap. The results of these tests are shown in Table I. Typical pressure traces at various temperatures are shown in Figure 4. From the results of the tests it appears that the burn time at -65°F is not significantly different from the burn time at 70°F. The largest change in burn time and maximum pressure occurs at 500°F. The most significant occurrence at -65°F is the extent of drop off in pressure after the rupture disc gives way. This happens to be the most critical point for -65°F firings for the ignitor system being used. For these quantities of ignitor and sustainer material there is a certain exhaust nozzle diameter above which combustion will not be sustained and for which a hang-fire will result. A hang-fire is defined as a firing in which a period of time, for example, 30 seconds, is required for the grain to catch up and burn after rupture of the disc. The maximum nozzle diameter, which is set by the requirement to avoid a hang-fire, alsc determines the maximum pressure which will be obtained at 500°F. Therefore, it can be seen that achievement of minimum spread between maximum pressure at -65°F and 500°F is dependent on pressure of rupture for the rupture disc, nozzle diameter, and quantities of ignitor and sustainer meterials. The rupture is affected not only by heat transfer to it from the hot gases but also by the extent to which it is oxidized by these gases. Therefore, its selection cannot be based solely upon its rupture pressure with a cold gas. Its location downstream of the main chamber of the gas generator and its susceptibility to changes in strength with temperature as well as oxidizing gases must be considered. It can be noted in Figure 4, for example, that rupture at 500°F (at the first extreme drop in the pressure curve) occurs at a lower pressure than for -65°F and ambient. The dip

TABLE I - TEST RESULTS FOR GAS GENERATOR FIRINGS WITH 1.25 INCH DIAMETER GRAINS
AeReCo 706D Propellant

| Run No. | Grain Wt. gms | Dia. In. | Length In. Grain 1 Grain 2 Grain 3 | Pressure Disk psi | Firing Temp F | Soak Time Hrs. | Transfer Interval Min. | Nozzle Dia. In. | Residue Wt. gms | Max. Press. psi | Burn Time Sec. ** | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | All sustainers bonded to grains. |
| 1 | 50.3*<br>48.0<br>47.6 | 1.250 | 2.044<br>2.036<br>2.028 | 1000 | +76 | --- | ---- | .193 | 27.5 | 3300 | .38 | |
| 2 | 50.9*<br>47.4<br>47.4 | 1.250 | 2.062<br>2.039<br>2.034 | 1000 | +78 | --- | ---- | .193 | ---- | 400 | --- | Perforations did not extend into sustainer. Sustainer burned but grains did not. |
| 3 | 50.2*<br>47.4<br>47.4 | 1.250 | 2.054<br>2.025<br>2.011 | 1200 | +60 | --- | ---- | .193 | 26.7 | 1920 | .29 | Went from .004" to .005" Rupture disc |
| 4 | 50.5*<br>47.6<br>47.6 | 1.250 | 2.032<br>2.023<br>2.023 | 1200 | +68 | --- | ---- | .193 | 28.6 | 2060 | .53 | Glued on 4 nichrome wires to keep grain from touching gen. |
| 5 | 51.1*<br>48.0<br>47.2 | 1.250 | 2.055<br>2.036<br>2.035 | 1200 | +74 | --- | ---- | .193 | ---- | 1050 | --- | Perforations did not extend into sustainer. Sustainer burned but grains did not. |
| 6 | 50.2*<br>47.6<br>47.5 | 1.245 | 2.055<br>2.030<br>2.028 | 1200 | +76 | --- | ---- | .193 | 28.2 | 1980 | .56 | |
| 7 | 49.7*<br>47.4<br>47.1 | 1.250 | 2.040<br>2.017<br>2.036 | 1200 | +76 | --- | ---- | .193 | 30.2 | 2070 | .57 | |
| 8 | 50.3*<br>47.6<br>47.6 | 1.248 | 2.040<br>2.036<br>2.031 | 1200 | +77 | --- | ---- | .193 | 29.9 | 2090 | .54 | |

* Includes Sustainer Weight
** Measured at 50 percent of maximun pressure

TABLE I (Cont) - TEST RESULTS FOR GAS GENERATOR FIRINGS WITH 1.25 INCH DIAMETER GRAINS
AeReCo 706D Propellant

| Run No. | Grain Wt. gms | Dia. In. | Length In. Grain 1 Grain 2 Grain 3 | Pressure Disk psi | Firing Temp F | Soak Time Hrs. | Transfer Interval Min. | Nozzle Dia. In. | Residue Wt. gms | Max. Press. psi | Burn Time Sec. ** | Remarks All sustainers bonded to grains. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 9 | 49.8*<br>47.6<br>47.2 | 1.247 | 2.063<br>2.032<br>2.026 | 1200 | +78 | --- | ---- | .193 | 29.6 | 1920 | .60 | |
| 10 | 51.0*<br>47.6<br>47.6 | 1.247 | 2.040<br>2.034<br>2.023 | 1200 | +79 | --- | ---- | .193 | 30.0 | 2080 | .61 | |
| 11 | 50.0*<br>46.7<br>46.6 | 1.247 | 2.066<br>2.056<br>2.048 | 1200 | -65 | 25.0 | 6.0 | .193 | 27.0 | 2590 | .52 | First firing at -65°F of 1/4" grain. No excessive plugging of screen. Grains for 11 through 15 fired with 44.7% shavings. |
| 12 | 49.7*<br>46.8<br>46.7 | 1.247 | 2.068<br>2.063<br>2.055 | 1200 | -65 | 71.7 | 3.5 | .193 | 28.0 | 2430 | .49 | |
| 13 | 50.4*<br>46.8<br>46.8 | 1.247 | 2.065<br>2.060<br>2.057 | 1200 | +90 | --- | ---- | .193 | 29.6 | 2640 | .28 | |
| 14 | 50.5*<br>46.7<br>46.1 | 1.247 | 2.071<br>2.062<br>2.047 | 1200 | +78 | --- | ---- | .193 | 28.5 | 2650 | .28 | |
| 15 | 49.7*<br>46.5<br>46.4 | 1.247 | 2.066<br>2.057<br>2.056 | 1200 | +500 | 2.5 | 6.90 | .193 | | 4040 | .20 | |
| | | | | | | | | | | | | |

* Includes Sustainer Weight
** Measured at 50 percent of maximum pressure

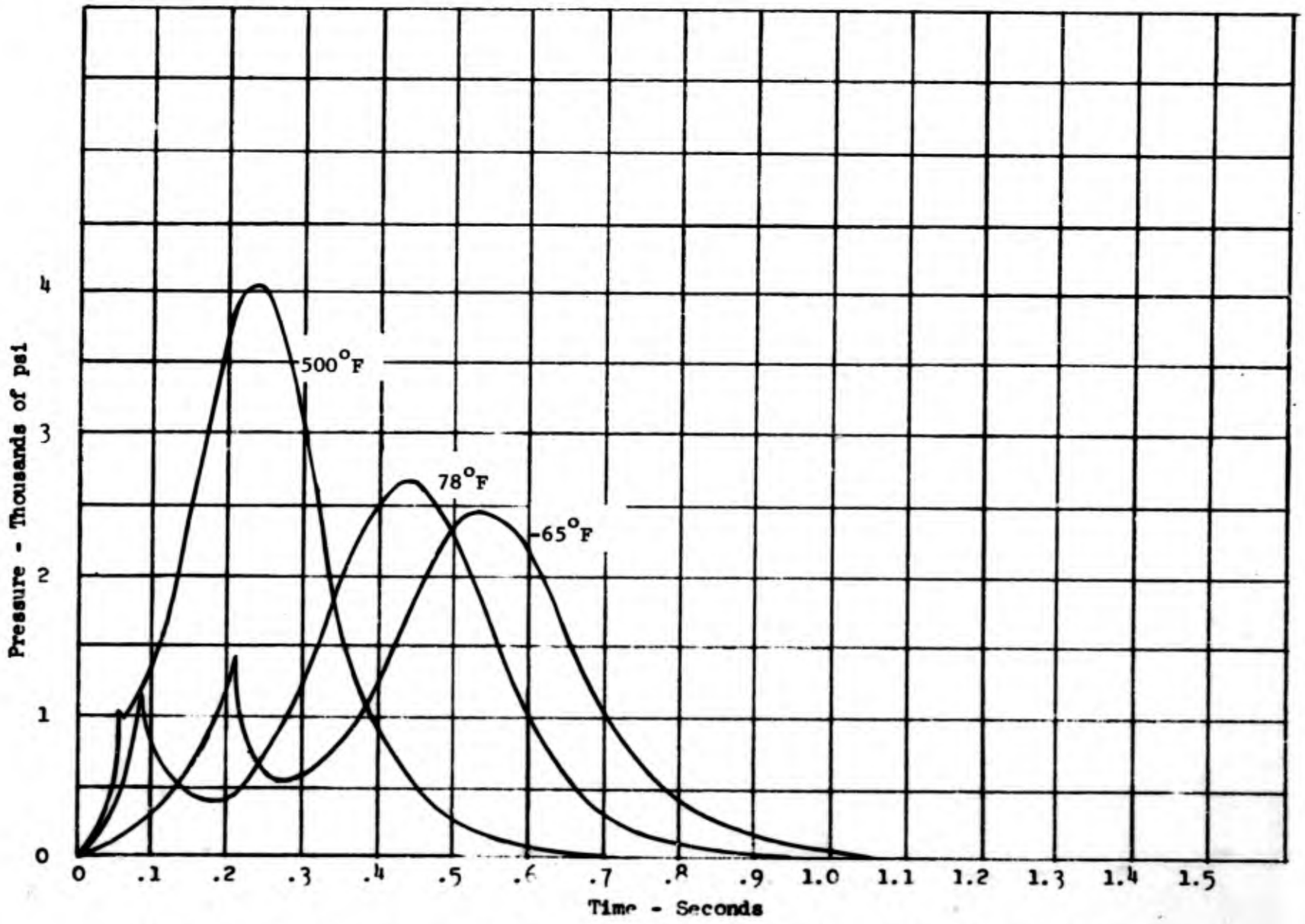


Figure 4 - Chamber pressure for 1.25 inch diameter grains at -65, 78, and 500°F

in the pressure curve after the rupture disc fails can be reduced by increasing the amount of sustainer material but at the expense of increased exhaust gas temperature. It was determined in these firings, that for the ignitor system used, a pressure spread of approximately 2000 psi can be achieved if a maximum pressure of 4000 psi is acceptable. It can be noted from runs 2 and 5 that difficulty was encountered in maintaining pressure and that the grains did not burn. This was attributed to the fact that the perforations were not drilled completely through the grain thereby failing to provide a maximum conical surface in the sustainer. This was determined by examining the grain to which the sustainer was originally attached as failure of the grain to burn resulted in preservation of the evidence. This is an area which will require close quality control and inspection. Because the 500°F firing provided the sought for performance, only one firing was made before proceeding to the evaluation of the 1.5 inch diameter grains.

Test Results With 1.5 inch Diameter Grain

The test pattern for this grain followed closely that for the 1.25 inch diameter grain with the exception that the nozzle size was changed during testing in an attempt to lower the spread between maximum pressure at -65°F and 500°F. As seen in Table II, the first three firings were with a .193 inch diameter nozzle which was increased first to a 0.228 inch diameter and then to a 0.234 inch diameter. The overall result of these changes was that it was found necessary to enlarge the carbon screen hole diameters and grooves to match the flow through the exhaust nozzle. This prevented having the screen openings and grooves constitute the major restriction rather than the exhaust nozzle. Particle build up in the screen holes and grooves was

TABLE II - TEST RESULTS FOR GAS GENERATOR FIRINGS WITH 1.5 INCH DIAMETER GRAINS
AeReCo 706D Propellant

| Run No. | Grain Wt. gms | Dia. In. | Length In. Grain 1 Grain 2 | Pressure Disk psi | Firing Temp F | Soak Time Hrs. | Transfer Interval Min. | Nozzle Dia. In. | Residue Wt. gms | Max. Press. psi | Burn Time Sec. ** | Remarks<br>All sustainers bonded to grains. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 80.0*<br>73.6 | 1.515 | 2.486<br>2.456 | 1200 | +80 | --- | ---- | .193 | 31.6 | 1970 | .43 | This grain was pressed without using shavings. |
| 2 | 80.6*<br>74.4 | 1.510 | 2.458<br>2.435 | 1200 | +72 | --- | ---- | .193 | 33.3 | 2780 | .30 | Grain pressed with 47.7% shavings. |
| 3 | 81.1*<br>75.2 | 1.508 | 2.503<br>2.491 | 1200 | +72 | --- | ---- | .193 | 32.1 | 2880 | .26 | This, and all following grains used 47.7% shavings. |
| 4 | 76.9*<br>70.2 | 1.508 | 2.492<br>2.476 | 1200 | +72 | --- | ---- | .228 | 31.4 | 2250 | .25 | Enlarged nozzle, and also screen holes from .098" to .110" |
| 5 | 82.0*<br>74.4 | 1.509 | 2.508<br>2.465 | 1200 | +72 | --- | ---- | .234 | --- | 1050 | .20 | Nozzle-enlarged Screen holes--.116". Perforations did not extend into sustainer. Grains did not burn. |
| 6 | 80.6*<br>74.2 | 1.511 | 2.487<br>2.481 | 1200 | +72 | --- | ---- | .234 | 33.0 | 1930 | .24 | |
| 7 | 81.2*<br>74.6 | 1.512 | 2.510<br>2.463 | 1200 | +72 | --- | ---- | .234 | 33.7 | 1800 | .33 | |
| 8 | 81.5*<br>74.2 | 1.510 | 2.502<br>2.410 | 1200 | -65 | 23.2 | 4.0 | .234 | 31.1 | 1280 | --- | Hang-fire grain burned in spurts. |

* Includes Sustainer Weight
** Measured at 50 percent of maximum pressure

TABLE II (Cont) - TEST RESULTS FOR GAS GENERATOR FIRINGS WITH 1.5 INCH DIAMETER GRAINS
AeReCo 706D Propellant

| Run No. | Grain Wt. gms | Dia. In. | Length In. Grain 1 Grain 2 | Pressure Disk psi | Firing Temp F | Soak Time Hrs. | Transfer Interval Min. | Nozzle Dia. In. | Residue Wt. gms | Max. Press. psi | Burn Time Sec. ** | Remarks<br>All sustainers bonded to grains. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 9 | 81.3*<br>74.7 | 1.511 | 2.500<br>2.462 | 1200 | +500 | 5.25 | 5.0 | .234 | 29.6 | 3450 | .19 | |
| 10 | 80.7*<br>74.2 | 1.510 | 2.510<br>2.479 | 2200 | -65 | 24.1 | 4.0 | .234 | 31.2 | 2190 | .22 | |
| 11 | 82.9*<br>71.2 | 1.512 | 2.614<br>2.362 | 2200 | -65 | 8.25 | 5.0 | .238 | 30.6 | 1075 | .96 | Nozzle size increased to .238" |
| 12 | 81.5*<br>74.0 | 1.511 | 2.489<br>2.467 | 2200 | +500 | 8.25 | 5.0 | .238 | 27.5 | 3890 | .19 | Screen holes were plugging excessively |
| 13 | 81.6*<br>74.3 | 1.509 | 2.486<br>2.468 | 2200 | +500 | 3.01 | 4.0 | .238 | 30.4 | 920 | .79 | Screen grooves cut deeper and wider. Grain may not have reached 500°F |
| 14 | 81.5*<br>74.9 | 1.509 | 2.481<br>2.438 | 2200 | +500 | 7.15 | 8.0 | .238 | 28.5 | 2300 | .25 | Screen same as for firing 13. |
| 15 | 81.5*<br>74.6 | 1.509 | 2.495<br>2.455 | 2200 | +500 | 5.82 | 5.0 | .234 | 27.4 | 2300 | .40 | |
| | | | | | | | | | | | | |

* Includes Sustainer Weight
** Measured at 50 percent of maximum pressure

a major factor in screen blockage. It can be seen that through firings 1 through 12 the maximum pressure obtained was 3890 psi which occurred at run 12. This high pressure was attributed to build up in the screen holes and grooves. Subsequent firings, even at 500°F, resulted in erratically lower pressures (i.e., 920 psi in firing 13, and 2300 psi in firing 14, both at 500°F). After evaluation of all of the firings 1 through 15, it was concluded that with the ignition system being used, attempts to achieve maximum pressure less than 4000 psi at 500°F would not prove fruitful and that either a change in the perforation diameters and the number of perforations or an increase in the amount of ignitor would be required to reduce this maximum. With the approval of Walter Kidde and Company, it was decided to retain the existing system and to set the maximum pressure at 4000 psi, a pressure which is acceptable in the application for which the system was designed. This applies to both 1.25 inch and 1.5 inch diameter grains. The curves of Figure 5, show typical results for firings at -65°F, ambient, and 500°F for the 1.5 inch grain.

Comparison of Preceding Test Results With Those for 1.0 inch Diameter Grains

Test results for the one-inch diameter grain showed that a maximum pressure somewhat under 2000 psi (i.e., 1200 psi) could be tolerated and therefore a maximum pressure of 3000 psi was possible. This difference is attributed to the larger ullage for the larger grains and the greater ratio of propellant weight to sustainer weight. A check of $\pi_k$ for all systems indicates that there was very little change which partially substantiates these conclusions. A comparison of quantities of residue in the generator after firings indicates that the amount of residue is approximately five times that obtained with the smaller grains and therefore, that the amount of residue is directly proportional to the initial weight of the grains. As with

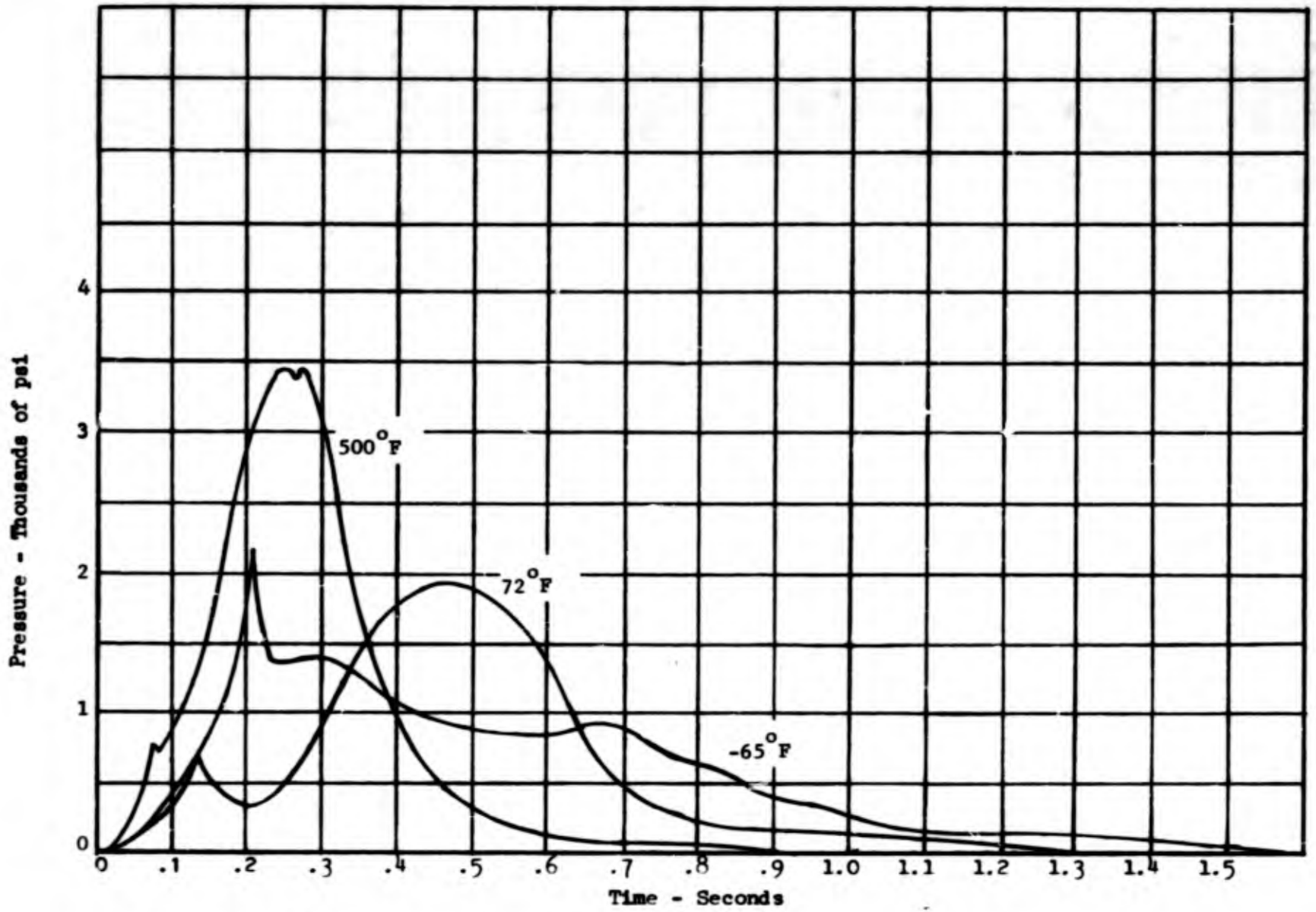


Figure 5 - Chamber pressure for 1.5 inch diameter grains at -65, 72, and 500°F

the one-inch grains, the incorporation of shavings from previous drillings into the grain mixture changes the performance characteristics of the grains but the change is consistent and may be accounted for in the gas generator design. It is important therefore, to note whether or not shavings have been added and that the quantity of shavings not be changed once the generator design is frozen. It can be reasonably concluded that maximum pressures of 3000 psi while still maintaining ignition at -65°F can be obtained. However, this probably would require a departure from the more conventional number of seven perforations and would also require modification in the ignition system probably with sustainer caps being attached to each grain rather than to the lead grain as is the case here. The results for the 1.5 inch diameter grain indicate that with increasing chamber ullage the performance becomes increasingly less predictable at -65°F for the ignition system configuration being used.

There is no reason to expect that the larger grains would perform differently in the environment of moisture, vibration, temperature cycling, etc., than the initial grains and therefore, these factors were not considered in the evaluation. The utilization of two and three segment grains is a departure from the single one-inch grain, but there appear to be no adverse results from this difference. No attempt in the tests at Aerospace Research Corporation was made at glueing the grains together or to determine the effect of doing so. As noted, wires were glued to the grains to stand them off from the walls of the generator. This was also done with the one-inch grains. It is probable that stand offs will be required in any application in order to hold the grain firmly during severe vibration or shock.

## SECTION V

## CONCLUSIONS AND RECOMMENDATIONS

The new systems as designed and evaluated have performance characteristics similar to the system evaluated in Phase I and should perform equally well in the scaled up application. The primary difference is that there is a maximum chamber pressure of 4000 psi for the two new systems as designed rather than 3000 psi as was achieved with the Phase I system. The performance of the 1.5 inch diameter grains is less predictable than the performance of the 1.0 and 1.25 inch diameter grains and this is attributed to the greater chamber ullage caused by the larger diameter perforations of the 1.5 inch diameter grains.

As the primary area of difficulty has been with increased chamber ullage, it is recommended that further experimentation be carried out to evaluate the best methods of reducing ullage.

APPENDIX I

BUREAU OF EXPLOSIVES

ASSOCIATION OF AMERICAN RAILROADS

REPORT FROM CHEMICAL LABORATORY

ON

AeReCo 706D

# BUREAU OF EXPLOSIVES

ASSOCIATION OF AMERICAN RAILROADS

REPORT FROM CHEMICAL LABORATORY

T. C. GEORGE. DIRECTOR AND CHIEF INSPECTOR

C. W. SCHULTZ. CHIEF CHEMIST

FILE NUMBER 16-2317-1
15-145

LABORATORY NUMBER 60375

EDISON, N. J., December 20 1968

Flammable Solid

AeReCo 706D

AEROSPACE RESEARCH CORPORATION

Samples of molded units identified as AeReCo 706D were received from Aerospace Research Corporation of Roanoke, Virginia.

On October 29, 1968 a report was issued on these units (Lab. No. 60298) in which they were classed as Class B Explosives. At that time nothing was known about the packaging of the items.

As a result of discussions with the manufacturer on the burning characteristics and packaging of the units, it was decided to conduct some more tests with a view to classing them as Flammable Solids.

Each unit had about 10 grams of ignition compound on one end. This could not be ignited with a match. It could be ignited with the flame of a laboratory burner and burned extremely rapidly but did not ignite the main part of the grain.

The main part of the grain could be ignited with a burner flame and would burn for a short time and then go out. This was repeated several times and at no point did the burning become self-sustaining.

Portions of the ignition mixture and the grain were placed in the Brass Block Apparatus and heated to 600°F. Neither of the mixtures ignited at this temperature.

Packaging will be in accordance with §173.154(a)(8) or (a)(12) of the Regulations.

In view of the high temperature stability of this material and the fact that even if ignited it does not continue to burn when under no greater than atmospheric pressure, it is considered that material represented by this sample may be properly described as Flammable Solid. NOS and classed as a Flammable Solid under the DOT Regulations.

C. W. Schultz

(EMM)

# BUREAU OF EXPLOSIVES

ASSOCIATION OF AMERICAN RAILROADS

REPORT FROM CHEMICAL LABORATORY

T. C. GEORGE, DIRECTOR AND CHIEF INSPECTOR

C. W. SCHULTZ, CHIEF CHEMIST

FILE NUMBER 15-145

LABORATORY NUMBER 60298

EDISON, N. J., October 29 1968

Propellant Explosive (Solid) Class B

AeReCo 706D

AEROSPACE RESEARCH CORPORATION

Samples of a material identified as AeReCo 706D were received from Aerospace Research Corporation of Roanoke, Virginia.

The samples were in the form of right cylinders 2 1/2" long by 1 1/2" diameter weighing 81 grams. Each cylinder had 7 three-eights inch diameter longitudinal holes running through it. One end was closed with a disc 1/8" thick.

The composition was not given.

The material was stable when maintained at 75°C for 48 hours.

A cylinder was initiated with a number 8 electric blasting cap in the central hole. It did not explode but portions of it ignited.

This test was repeated with the same result.

Two cylinders were placed in contact with each other on a bed of kerosene-soaked sawdust which was ignited. When the fire reached the samples they seemed quite resistant to ignition. After a while they did take fire and burned quite rapidly in spurts with short periods of non-burning in between. They burned with a bright green flame.

Material represented by these samples is properly described as Propellant Explosives (Solid) Class B and classed as Class B Explosives under the DOT Regulations.

C. W. Schultz

(EMM)

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| | AF Aero Propulsion Laboratory<br>Wright-Patterson AFB, Ohio 45433 |

13. ABSTRACT

Advanced aircraft operating in supersonic and hypersonic flight regimes impose many environmental problems on aircraft subsystems. Fire extinguishing equipment will be required to operate efficiently over a -65° F to 500° F temperature range. To meet this requirement, a full scale Pyrotechnic Fire Extinguishing System was designed, developed and fire tested under simulated flight conditions. This Pyrotechnic Extinguishing System (wherein pyrotechnic pressurization replaces nitrogen as an energy source) will function effectively under extreme environmental conditions and its performance on a weight effectiveness basis is superior to that of the standard nitrogen pressurized units.

DD FORM 1 NOV 65 1473

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