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Techniques in Smoke Application

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ETHYL CORPORATION RESEARCH LABORATORIES

TECHNICAL REPORT AFATL-TR-67-163

OCTOBER 1967

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TECHNIQUES IN SMOKE APPLICATION

U. A. Lehikoinen
D. J. Stoy

FOREWORD

This is a comprehensive report of work carried out during the period 20 June 1966 to 20 June 1967 at Ethyl Corporation Research Laboratories, 1600 West Eight Mile Road, Ferndale, Michigan 48220 and Avco Corporation Ordnance Division, Sheridan Street, Richmond, Indiana 47374 under Contract AF 08(635)-6001 (Ethyl Project 90223 - GR 67-33) with the Air Force Armament Laboratory, Eglin Air Force Base, Florida. Program Monitor for the Air Force was Captain Kenneth K. Jue (ATCC).

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Edward D. Smith, Lt Col
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for Chief, Bio-Chemical Division

ABSTRACT

The objective of this research was to develop nontoxic, noncorrosive, and nonirritating aluminum alkyl-based smokes and a delivery system adaptable to the SUU-13/A system for low-altitude, high-speed aircraft. The selection of initial candidate smoke agents was based on our experience with similar agents for other applications. Quantitative evaluation of their smoke densities by TOP (total obscuring power) measurements and smoke-tunnel analysis proved them to be comparable to or superior to agent FM (titanium tetrachloride), a standard military screening smoke. All agents have low pour points (< -50°C), low cloud points (< -70°C), and low fire and flash points (-40 to -60°C). Two of the most promising agents (90223-7 and 90223-9) were subjected to storage surveillance tests at -40°F, ambient temperature, and +160°F for a period of three months. The agents showed excellent storage stability. Other studies showed that the smoke from these two agents has no deleterious effect on seven metals and eight polymers. Thermal stability tests for several hours at 212°F indicated that agents 90223-7 and 90223-9 are stable. The prototype disseminator is a cylindrical aluminum container 4-5/8 inches in diameter and about 9-3/4 inches long. The top of the container contains three fuel oil spray nozzles. A pyrotechnic gas generator actuates a Bellofram diaphragm, which forces agent out of the nozzles as fine sprays. The disseminator generates a dense white smoke for 6-8 minutes. The units have been fired successfully from SUU-13/A ejector tubes and functioned normally. They also performed satisfactorily after 40-foot drop tests on steel. Two large-scale field tests with these units and our agents demonstrated the feasibility and effectiveness of this smoke dissemination technique. Candidate agents 90223-7 and 90223-9 fulfill the requirements of the contract. The disseminators are adaptable to the SUU-13/A system. The impact and ejection tests of the units show their durability under conditions simulating an aerial drop from low-altitude, high-speed aircraft. We recommend that slight modifications of the present unit be made to improve its orientation in water, to eliminate the need for a Bellofram diaphragm, and to increase its structural integrity. We also advise conducting larger-scale, static field tests to more fully evaluate the smoke screens under various environmental conditions and submitting filled prototype units to the U. S. Air Force for evaluation when launched from aircraft.

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SECTION I

INTRODUCTION

1. OBJECTIVE

The objective is to develop a smoke screening technique for low-altitude, high-speed aircraft using a nontoxic and noncorrosive smoke. Other criteria include:

- a. Dispersal from present standard Air Force delivery systems.
- b. An obscuring screen at least one-half mile in length.
- c. Maximum horizontal visual penetration of 25 feet.
- d. Minimum smoke cloud height of 50 feet.
- e. Persist for at least 10 minutes in a 0-2 mph wind.
- f. Equally effective operation over land, water, or mud.
- g. Optimum weight of filled smoke dispenser is 750 pounds.
- h. Delivery from aircraft flying from 400-600 KIAS.

2. CONCEPT

After examination of present Air Force delivery systems, it was decided the SUU-13/A system was the most promising and versatile. It is compatible with high-speed aircraft and its dispensing capability encompasses rather wide ranges. Our purpose was to design delivery units that would effectively disperse our smoke agents and be readily adaptable to the SUU-13/A ejector tubes.

3. BACKGROUND

Ethyl Corporation has previously undertaken both government-sponsored and proprietary research in methods of producing nontoxic, non-corrosive, and nonirritating smokes. Recent examples are Contracts DA 18-001-AMC-526(X) and DA 18-001-AMC-747(X) for the U. S. Army Limited War Laboratory, which led to the development of effective aluminum alkyl-based smoke formulations. One of these agents has undergone extensive testing at the U. S. Naval Ordnance Test Station, China Lake, California. The smoke has performed well during dissemination from Mark 12 tanks mounted on both rocket sleds and jet aircraft.

The candidate agents have a composition based on a mixture of hydrocarbon oils and alkylaluminum compounds. They are mobile and amber-colored liquids. When disseminated in the air, these aluminum alkyls react with oxygen and moisture to form solid particles of aluminum oxides, aluminum hydroxides, and aluminum alkoxides. During this reaction, heat is generated, which partly vaporizes the diluent oil. When the oil recondenses as small droplets, a fog oil effect enhanced by solid reaction particulates is obtained. The obscuring power of the smoke increases when the agents are disseminated through spray nozzles.

SECTION II

EVALUATION TECHNIQUES

1. CANDIDATE AGENTS

The criteria for evaluating and choosing agents were their physical and chemical properties and obscuring ability. Disseminator assessment was based on dissemination characteristics, generation time, and compatibility with both aluminum alkyl smoke agents and SUU-13/A system.

The methods used to determine the potential merit and acceptability of the candidate agents were:

a. Field Tests

Preliminary field tests were run on all candidate agents. A 200-ml capacity brass unit, equipped with top and bottom toggle valves and a fuel oil nozzle, was charged with agent. The top valve was used to pressurize the unit, and the bottom valve was used to control the flow of agent. These tests gave qualitative data on smoke color, smoke density, and duration of smoke cloud.

b. Smoke Tunnel Tests

Quantitative measurements of the obscuring ability of candidate agents were made in the smoke tunnel. In these tests, 75 ml of the agent was atomized, in several "bursts", into an airstream flowing in a 14-inch diameter, vertical transite pipe, 6 feet long. Agent dissemination was from the top of the pipe, again using brass dispensers as in the field tests. The air flow rate was kept constant.

The smoke tunnel, as shown in Figure 1, is mounted vertically in a supporting structure. Within one foot of the bottom of the tunnel and projecting into the tunnel are telescoping aluminum tubes, equipped with plexiglas windows. These are used to establish a fixed optical path of suitable length through the smoke for intensity measurements. In our tests, a path of 1.75 inches seemed to give the greatest sensitivity.

Smoke densities are measured with an Autotron Model P8L3/E8BC photocell-light source combination. The output from the photocell was amplified and recorded by a Mosley Autograph Model 680 strip chart recorder. This gave a time-transmission record.

The system was calibrated at two points, 0 and 100% transmission. The zero transmission point was obtained by adjusting the recorder to zero with the light source off and only the air flowing. The 100% transmission point was obtained by imposing a fixed voltage on the light source and adjusting the recorder span for full travel as the light is switched off and on.

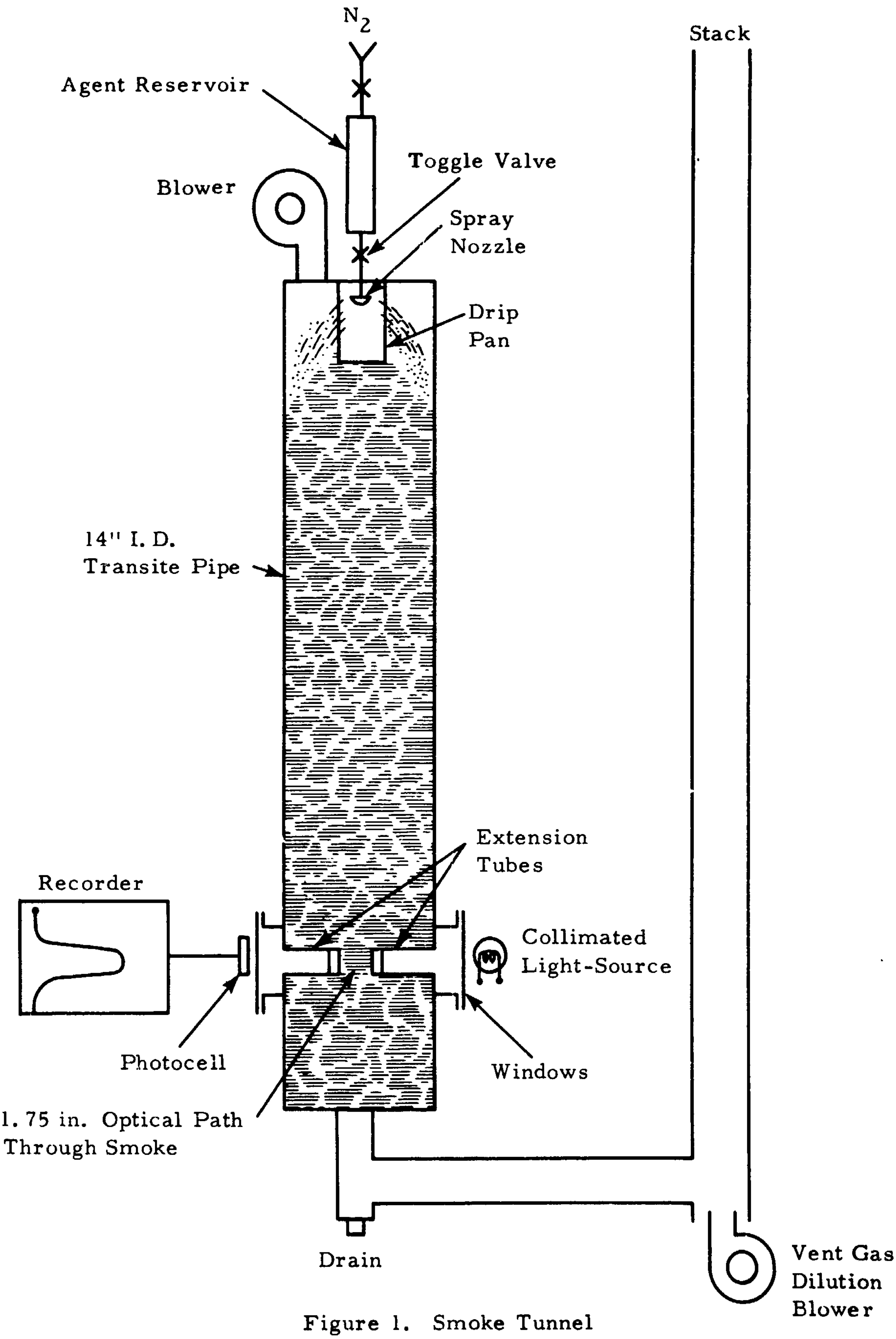

Figure 1. Smoke Tunnel

If we assume that all particles produced by smoke agents absorb or scatter light equally, it is evident that the intensity of the light received by the photocell must be proportional to the concentration of particles per unit volume. The proportionality factor will not necessarily be linear since, as particle concentration increases, more and more particles are shadowed by others and contribute to opaqueness by dispersive processes.

Thus, the area of the time-transmission curve for an agent is related to the number of particles produced by the agent. This value also can be related to the weight or volume of the feed. Therefore, the area under the light transmission-time curve is a measure of the amount of smoke produced; the height of the curve is related to the screening material's opaqueness (smoke density), and the time to its persistency.

In these tests, 75 ml of the candidate agent was disseminated. Because the volume of the tunnel was small, no meaningful density-persistence curves could be obtained by discharging the full 75 ml of the agent at one time. Therefore, the agent was disseminated incrementally under 75-psig nitrogen pressure in 4-second or 5-second bursts until exhausted. The duration of the burst depended on the smoke density and was adjusted to give a measurable peak. (Overly long bursts would saturate the tunnel.)

Sufficient time was allowed between bursts for the curve to reach baseline or level off near the baseline. Between runs, the windows were carefully cleaned and the instrument recalibrated to guarantee meaningful comparisons of candidate agents with a secondary standard (90622-T, another aluminum alkyl-based agent). The secondary standard was used rather than agent FM or agent FS because it is more easily and safely disseminated, and does not corrode test equipment. Agent 90622-T has been directly compared to Agent FM in previous research.[1] This work was done with the same equipment as was used in the present research.

Agent 90622-T was assigned a relative obscuring power value of 100 percent. This value represents the total area under the time-transmission curve. When agents have a mass density close to that of 90622-T, the area of their time-transmission curve can be compared to that of 90622-T, thereby obtaining a percent relative obscuring power. A similar value is referred to as the volumetric smoke number (VSN).

$$VSN = \frac{10.0 A_A}{A_{FM}}$$

where A_A is the area under the agent curve and A_{FM} is the area under the FM curve.

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1 "Organometallic Screening Materials", U. A. Lehikoinen, M. E. Gluckstein, Contract DA 18-001-AMC-747(X), Ethyl Corporation Final Report GR 66-14, January 1966.

(FM is arbitrarily assigned a VSN of 10 for equal volumes of agent and FM). However, this parameter does not permit an evaluation on an equal-weight basis when a significant difference in mass density exists. Therefore, a second parameter also was used, the mass smoke number (MSN):

$$MSN = 10 \frac{A_A}{A_{FM}} \cdot \frac{\rho_{FM}}{\rho_A}$$

where A_A is the area under the agent curve, A_{FM} is the area under the FM curve, ρ_{FM} is the density of FM and ρ_A is the density of the agent. Thus, higher MSN and VSN values are associated with better obscuration.

c. Total Obscuring Power (TOP)

Total obscuring power (TOP) is defined as the product of the optical density of the smoke and volume of smoke produced per unit weight.[2]

$$TOP = \frac{V\left(\frac{1}{D}\right)}{W}$$

where D is the distance to target in feet, V is the volume of test chamber in cubic feet, and W is the weight of agent in pounds.

The test chamber consisted of a room (8' x 8' x 20') lined with black polyethylene film (see Figure 2). Brass units were charged with 100 ml of the agent and placed on the test stand. The contents were discharged by nitrogen pressure through a spray nozzle, and the resultant smoke was distributed by two fans. At one-minute intervals, the light source was moved along the calibrated rod until the bulb was barely visible, and distance readings were taken. All candidate agents and agent FM were evaluated by this method.

Agent FM and two candidate agents were disseminated underwater. A five-gallon drum was filled with water and brass units were charged with 800 ml of the agent. The nozzle of the brass unit was placed just below the water's surface and oriented downward. Measurements were made in a manner analogous to those in aerial dissemination studies.

d. Cloud and Pour Point

Cloud and pour points were determined by ASTM Method D97. The cloud point of a liquid is defined as the temperature at which phase separation begins when a liquid is chilled under definite prescribed conditions. This test consists of chilling the liquid slowly in a cooling bath and visually checking it for cloudiness after each 2°F drop in temperature.

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[2] Finklestein, Leo. History of Research and Development of the Chemical Warfare Service in World War II.

A - Fans
B - Test Stand
C - Light Source
D - Calibrated Rod
E - Observation Window
F - Nitrogen Tank

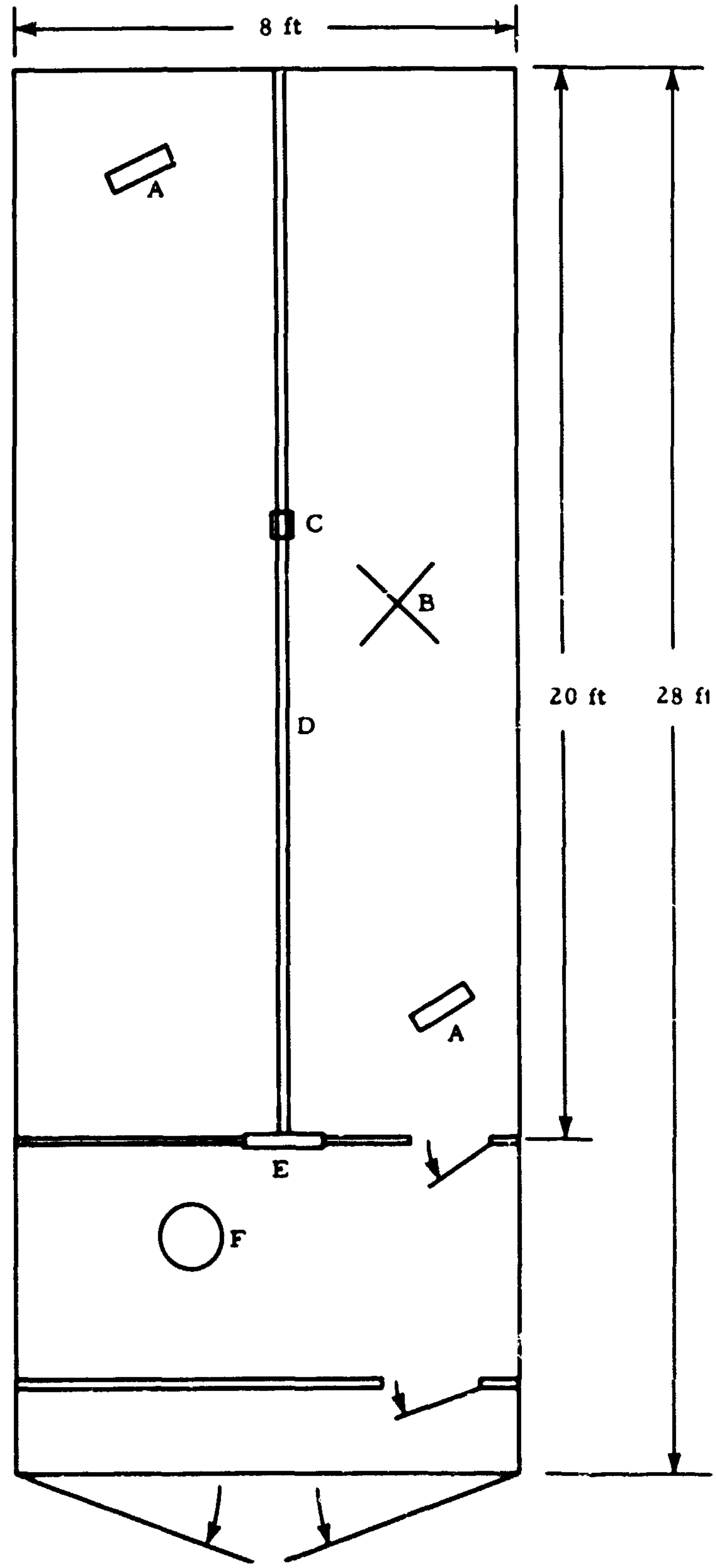

Figure 2. (TOP) Total Obscuring Power Apparatus

The pour point of a liquid is the lowest temperature at which the liquid will pour or flow when it is chilled, without disturbance, under definite prescribed conditions. In this test, the liquid is slowly chilled in a cooling bath. After every 5°F drop in liquid temperature, the test vessel is carefully tilted to ascertain whether there is a movement of the liquid in the vessel. This is continued until a point is reached at which the liquid shows no movement when the test vessel is held in a horizontal position for exactly 5 seconds. The pour point is defined as being 5°F above this solid point.

e. Flash and Fire Points

Fire points were determined by the Cleveland Open Cup Method, ASTM D92. A test cup is charged with liquid agent and cooled by a dry ice-acetone cooling mixture. A small test flame is passed over the cup after each 5°F rise in temperature. When a flash appears on the surface of the liquid, the temperature is recorded as the flash point. After determining the flash point, the test flame is applied at specified intervals until the liquid smoke agent ignites and continues to burn. The temperature at which ignition occurred is recorded as the fire point.

In testing our candidate agents, we found that the flash always led to continued burning. Thus, only fire points were recorded.

f. Storage Tests

Two candidate agents, 90223-7 and 90223-9, were stored at -40°F, ambient temperatures, and 160°F for three months. They were then removed and evaluated in the TOP apparatus to compare TOP values with freshly prepared agent. The storage vessels were 300-ml Kjeldahl flasks, each charged with 200 ml of the agent. The flasks were kept under a slight positive nitrogen pressure, cooled in dry ice to reduce the vapor pressure of the agent, and then fusion-sealed and placed in storage.

g. Particle Size and Composition of Smoke

Two separate runs were made in the smoke tunnel using candidate agents 90223-11 and a mixture of 90223-1 and 90223-2. Brass units and 2.00 GPH 60°R spray nozzles also were employed. Samples of the smoke were drawn from the tunnel by a copper tubing probe and vacuum pump and then collected on 0.22 μ millipore filter paper. The samples were washed several times with hexane and dried by a slow nitrogen flush. Particle size was determined by X-ray analysis, electron diffraction, and microscopic techniques. Composition was determined by elemental analysis.

h. Corrosion Studies

An elementary study was undertaken to determine if the smoke from agents 90223-7 and 90223-9 had any detrimental effects on seven metals and eight polymers. Two analogous sets of samples were prepared, one for testing and the other as a control set. The sample pairs were taken from a single piece of each material to ensure uniformity and identical past history. The surface of each metal sample was cleaned with steel wool.

Each sample was then rinsed in hexane and allowed to dry before weighing. All polymer samples also were cleaned and weighed prior to test initiation. Over a 30-day period, the test set was exposed to smoke on 13 separate occasions. For each exposure, 800 ml of the agent was used, with exposure lasting about two hours. All testing was done in the TOP apparatus. At all other times, the two sets were stored together.

2. SYSTEM DESIGN

The program for system design proceeded concurrent to the development of a suitable smoke agent. The size, shape, and basic design of the disseminator were relatively fixed by both the SUU-13/A system and the physical nature of the smoke agents. However, there were several parameters that could be varied.

Table I shows the effects of system variables on smoke dissemination. The pressure and nozzle system jointly control both the rate of flow of the liquid agent and the spray pattern. The spray pattern, rate of flow, and candidate agent all affect the smoke pattern. The viscosities and densities of the alkylaluminum smoke agents are almost identical. Therefore, flow rates and spray patterns do not change significantly when various smoke agents are employed.

TABLE I. EFFECTS OF SYSTEM VARIABLES ON SMOKE DISSEMINATION

Variables		Effects		
		Flow Rate	Spray Pattern	Smoke Pattern
Nozzle system	Nozzle type		x	x
	Nozzle size	x	x	x
	Number of nozzles	x	x	x
Pressure		x	x	x
Agent				x

a. Nozzle System

Two basic designs were tested with readily available oil burner nozzles and brass plugs modified by drilling holes approximately 0.001 inch in diameter. Spray nozzles, flow rated from 0.40 to 5.00 gallons per hour at 100 psi, were tested on brass units and workhorse models of the steel disseminator. Single-nozzle and tri-nozzle systems were tested. Again, brass units and workhorse models were used while varying the nozzle size and disseminating pressures.

b. Pressure Tests

The effects of pressure on the spray and smoke patterns and on flow times were studied. These results were used as guidelines by Avco in development of the pyrotechnically actuated gas generator.

3. SMOKE GENERATOR

Avco Ordnance Division built 2 all-steel workhorse generators and 32 aluminum units. The workhorse models were used in evaluating nozzle variations and pressure curves produced by the pyrotechnic generator. Four aluminum units were tested under various environmental conditions in studying dissemination times and smoke patterns. Twenty units were used in large-scale field tests to evaluate the proposed smoke screening technique. The remaining eight units were used as follows:

a. Mechanical Functions and Pressure Curves

Two units were used to determine mechanical function and pressure curves.

b. Hydrostatic Tests

The two units also were used in hydrostatic tests to determine the pressure required to rupture the units and to determine the safety margin.

c. Drop Tests

Four fully-loaded units were subjected to 40-foot drop tests, examined for damage, and then actuated.

d. Ejection Tests

Two units were ejected from SUU-13/A ejector tubes to check ejection velocity, fuze and vane behavior, and unit function on target. They were conducted by fastening the loaded SUU-13/A ejector tube to a steel plate (10" x 10" x 1/2"). The plate was then set in a channel iron holder that was staked to the ground. The top edge of the plate was backed up with a concrete block for additional stability.

The smoke generator unit, with an "O" ring in the pusher plate groove, was inserted into the SUU-13/A tube after cocking the firing mechanism and folding the vanes along its sides. The "O" ring allows for proper ejection of the unit by maintaining a tight gas seal at the pusher plate.

The closure cup, with its "O" ring, performs three functions:

1. Provides an environmental seal at the open end of SUU-13/A ejection tube.

2. Provides a mounting for the shear pins.

3. Provides the back-up for the nozzle sealing discs.

When the SUU-13/A ejection charge is fired, the gas pressure exerted on the pusher plate forces the smoke generator unit aginst the closure cup, causing the shear pins to fail. The resulting "shot start" imparts sufficient velocity to the unit to provide safe separation from the aircraft.

After exit from the SUU-13/A ejection tube, the following functions occur:

1. The firing mechanism striker fires the M42 Primer, and the primer flash initiates the gas generator (time fuze).

2. The vanes unfold, causing the unit to orient itself in the air for landing on the pressure plate end.

3. The nozzles are unsealed when the closure cup is separated from the unit by the turbulence of the air.

The 15-second interval, while the gas generator is building up to a sufficient pressure for good smoke dissemination, allows time for the unit to land on the target area.

e. Compatibility with Smoke Agents

Literature is available on the compatibility of the construction materials used in the aluminum disseminators with aluminum alkyls.[3] These materials -- Viton, aluminum, and brass -- are not affected by aluminum alkyls. In our laboratory work, we have found that Circosol 410 oil and methylnaphthalenes do not affect brass or aluminum. Their effect on Viton was studied by immersing samples in methylnaphthalenes and Circosol 410 oil for a period of 90 days at 160°F, -40°F, and ambient temperatures.

Two tests were run in which the live agent was disseminated from a steel workhorse model. This was done to determine if there was any reaction between the generator gas and aluminum alkyl-based smokes.

The workhorse model was modified to incorporate three tubes leading from the nozzles to the bottom of the inner canister. The diaphragm was removed. A pipe was placed in the unit, leading from the chamber containing the pyrotechnic delay train to the upper part of the inner canister. The pipe was covered with tape to prevent leakage of the smoke agent from the reservoir. Upon actuation of the delay train, the tape was split and the evolving gases forced the agent through the tubes and out the nozzles.

Aluminum Alkyls and Other Metal Alkyls. Ethyl Corporation, New York

SECTION III

RESULTS AND DISCUSSION

1. SMOKE AGENTS

a. Composition of Smoke Agents

Thirteen candidate agents were prepared and evaluated during this program. Since results of previous work indicated that approximately 6-7 wt % aluminum content is necessary for adequate screening ability, we limited the range from 5.7 to 7.2 wt %. The complete compositions are summarized in Table II.

TABLE II. COMPOSITION OF CANDIDATE AGENTS

Candidate Agent	Weight Percent					
	TEA	TEA-DEAH	TEA-TIBA	α-MN	Mixed MN	Circosol 410 Oil
90223-1	25	--	--	15	--	60
90223-2	--	25	--	15	--	60
90223-3	--	--	30	15	--	55
90223-4	--	--	35	15	--	50
90223-5	--	--	38.3	7	--	54.7
90223-6	27.36	--	--	7	--	65.64
90223-7	--	25	--	7	--	68
90223-8	--	25	--	--	15	60
90223-9	25	--	--	7	--	68
90223-10	25	--	--	--	15	60
90223-11	--	--	35	7	--	58
90223-12	--	--	35	--	15	50
90223-13	--	--	30	7	--	63

TEA - Triethylaluminum
TEA-DEAH - A mixture of triethylaluminum and diethylaluminum hydride (28 ± 2% DEAH)
TEA-TIBA - Diethyl-i-butylaluminum; a disproportionation product of triethylaluminum and triisobutylaluminum prepared *in situ*
α-MN - Alpha-methylnaphthalene
Mixed MN - A mixture of methylnaphthalenes (57% β, 43% α)

b. Obscuration

The results of TOP measurements and smoke tunnel evaluation indicate that the obscuration produced by candidate agents is equivalent to or superior to that of agent FM. These data are summarized in Table III.

Underwater TOP measurements were made of Agent FM, 90223-7, and 90223-9. Agent FM did not produce any smoke. Smoke from the candidate agents was reduced 85% when compared to aerial dissemination.

TABLE III. OBSCURATION OF CANDIDATE AGENTS (AERIAL DISSEMINATION)

Agent	Smoke Tunnel MSN	Smoke Tunnel VSN	TOP (Mean), Sq ft/lb	Probable Error of Mean ** Sq ft/lb	Probable Error of Mean ** Percent
FM	10 *	10 *	629	35.2	5.6
90223-1	29.6	15.4	516	50.3	9.7
90223-2	44.3	20.5	564	20.5	3.5
90223-3	16.8	8.7	393	30.0	7.6
90223-4	34.0	17.5	655	24.0	3.7
90223-6	27.0	14.1	771	63.2	8.2
90223-7	31.8	16.4	612	35.2	5.8
90223-8	30.5	15.9	547	30.0	5.3
90223-9	30.5	15.8	565	75.0	13.3
90223-10	25.1	13.2	458	39.7	8.7
90223-11	38.5	14.6	788	39.8	5.1
90223-12	26.0	13.5	687	27.6	4.0
90223-13	--	--	416	35.8	8.4
90622-T	31.1	15.2	1066	54.4	5.1

* Arbitrarily assumed base value.

** Probable Error of Mean defines the range about the mean in which one-half of further measurements would fall.

MSN - mass smoke number
VSN - volumetric smoke number
TOP - total obscuring power

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c. Correlations between Composition and Obscuration

In earlier work, it was found that the amount of smoke generated depends on the aluminum content; i.e., the amount of smoke increases as the aluminum content increases from 0 to about 9 wt %. This conclusion was substantiated in this work and is reflected by Figure 3.

Figure 3 also shows the effects of variations in amount and composition of flame suppressant. Apparently, considering the concentrations involved, methylnaphthalenes reduce the amount of smoke, with β-methylnaphthalene having more of an effect than the alpha analog.

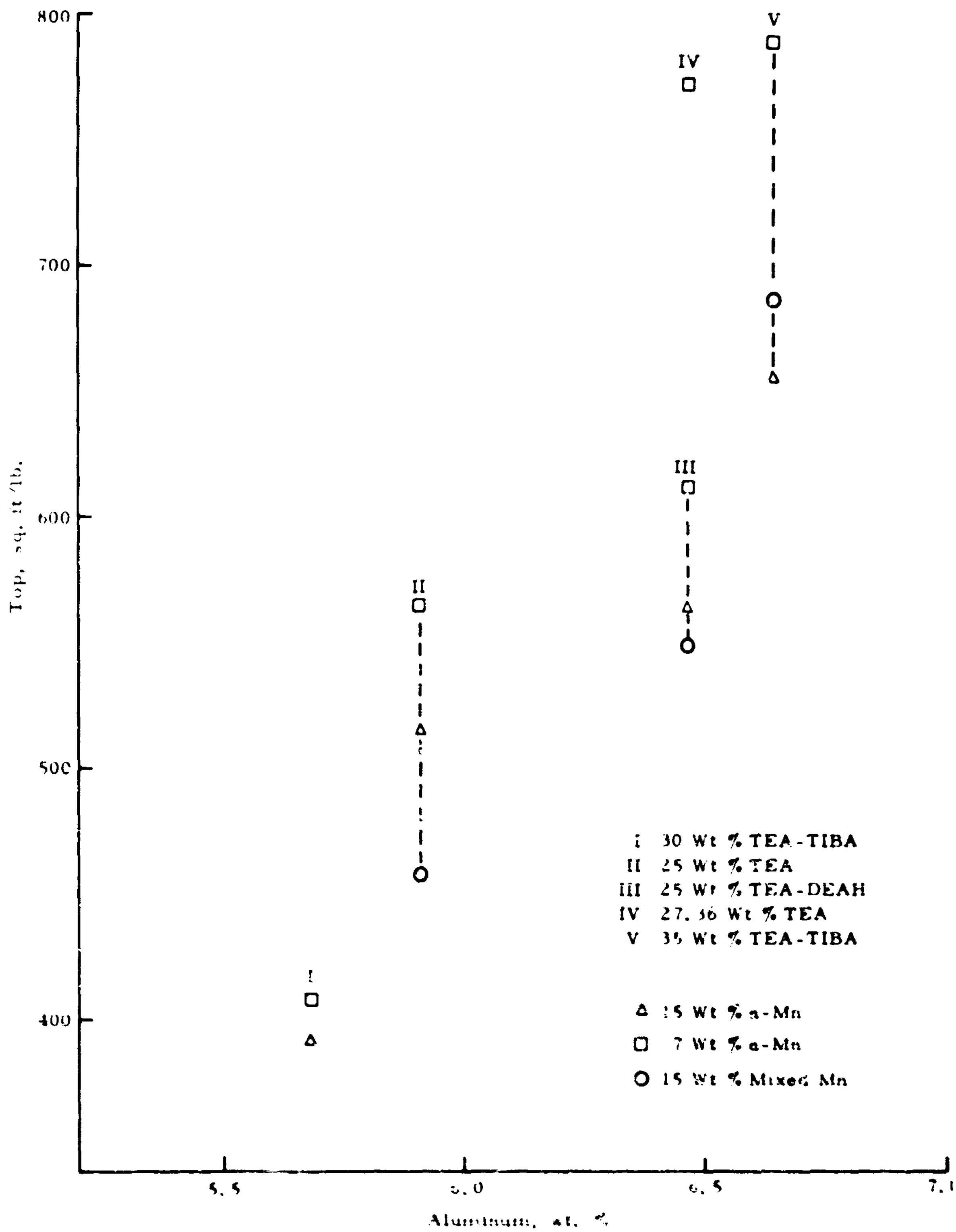


Figure 3. Dependence of Top on Both Weight Per Cent Aluminum and Methyl Naphthalene Content

d. Cloud and Pour Points

Results showed that our candidate agents have desirable low-temperature characteristics (see Table IV).

TABLE IV. CLOUD AND POUR POINTS OF CANDIDATE AGENTS

Agent	Cloud Point	Pour Point
90223-1	Below -70°C	-61 ± 2°C
90223-2	"	-66 "
90223-3	"	-60 "
90223-4	"	-58 "
90223-6	"	-50 "
90223-7	"	-58 "
90223-8	"	-60 "
90223-9	"	-52 "
90223-10	"	-58 "
90223-11	"	-58 "
90223-12	"	-70 "

e. Flash and Fire Points

The flash and fire points of the candidate agents tested were low, as shown in Table V.

TABLE V. FIRE POINTS OF SELECTED CANDIDATE AGENTS

Agent	Fire Point
90223-1	-48 ± 5°C
90223-2	-59 "
90223-9	-52 "
90223-10	-53 "

From these results, we concluded that the fire points of the other candidate agents would be in the range of -40°C to -60°C.

f. Storage Tests

The fusion seal on each of the Kjeldahl flasks was broken (after the contents reached room temperature), and the agents were used to charge grass units. Two TOP measurements for each agent were conducted, with the results shown in Table VI.

TABLE VI. TOP VALUES OF 90223-7 AND 90223-9 AFTER 90-DAY STORAGE

Sample	90223-7 TOP, sq ft/lb	90223-7 % Change	90223-9 TOP, sq ft/lb	90223-9 % Change
Cold	624	+ 2%	504	-11%
Ambient	570	- 7%	569	+ 1%
Hot	736	+20%	635	+12%
Fresh	612 ± 5.7%		565 ± 13%	

From these data we concluded that these storage conditions do not significantly affect the total obscuring power of agents 90223-7 and 90223-9, except possibly in one case when the sample of agent 90223-7 was stored at +160°F. A 20% increase in obscuring power appears to exceed the experimental error.

g. Particle Size and Composition of Smoke

Both electron diffraction and X-ray analysis showed that the smoke particulates are amorphous. Electron diffraction indicated crystallite size of 60-80 angstroms. Microscopically, the mean particle size was 0.2 μ, while the average agglomerate size ranged up to 1.5 μ.

Analysis of one sample showed 24 wt % Al, 14.6 wt % carbon, and 4.71 wt % hydrogen, with the remainder assumed to be oxygen. From these data and our knowledge of the materials, we believed that the reaction products were probably a mixture of aluminum ethoxides (e.g., Et_2AlOEt) and hydroxy aluminates (e.g., $EtAl(OH)_2$).

h. Corrosion Studies

We found that the smoke from candidate agents 90223-7 and 90223-9 did not significantly affect any of the test samples. After exposure was completed, each metal sample was rinsed in hexane, placed in an ultrasonic bath for about ten minutes, rinsed in acetone, dried, and then weighed. The weights and weight changes are summarized in Table VII. Examination of each metal surface, magnified 21x by a Bausch and Lomb microscope, revealed no differences between the test and control samples except for Inconel. It appeared that the Inconel control sample was somewhat more pitted than the test sample. Silicone rubber, Viton, neoprene, and natural rubber samples were tested for hardness with a Rex Model 1700 Durometer. Each pair exhibited identical hardness.

TABLE VII. RESULTS OF CORROSION STUDIES

Sample	Area, cm^2	$Weight_1$, g	$Weight_2$, g	$\Delta W(W_2-W_1)$	$\Delta W/Area$	$\Delta W/W_1 \times 100$
Teflon (control)	69.0	6.1938	6.1940	+0.0002	3×10^{-6}	0.003%
Teflon (test)	62.5	6.0445	6.0465	+0.0020	30×10^{-6}	0.033%
Viton	61.4	2.3488	2.3538	+0.0050	81×10^{-6}	0.213%
Viton	61.4	2.2120	2.2195	+0.0075	122×10^{-6}	0.341%
Polypropylene	74.0	2.1096	2.1117	+0.0021	28×10^{-6}	0.100%
Polypropylene	79.0	2.2033	2.2175	+0.0142	180×10^{-6}	0.642%
Polyethylene	35.2	2.5331	2.5367	+0.0036	103×10^{-6}	0.142%
Polyethylene	36.3	2.6016	2.6392	+0.0378	1040×10^{-6}	1.452%
Neoprene	61.8	7.4765	7.4668	-0.0097	-141×10^{-6}	-0.130%
Neoprene	67.6	8.1857	8.2473	+0.0616	911×10^{-6}	0.752%
Nylon	86.4	1.0050	1.0227	+0.0177	205×10^{-6}	1.761%
Nylon	85.6	0.8799	0.8976	+0.0177	207×10^{-6}	2.011%
Natural Rubber	48.9	12.8430	12.8620	+0.0190	388×10^{-6}	0.148%
Natural Rubber	47.1	13.8357	13.8558	+0.0201	427×10^{-6}	0.145%
Silicone Rubber	60.2	11.1817	11.1870	+0.0053	88×10^{-6}	0.047%
Silicone Rubber	58.8	10.7747	10.8660	+0.0913	1550×10^{-6}	0.847%
Copper	48.4	18.4437	18.4455	+0.0018	37×10^{-6}	0.098%
Copper	48.4	17.4715	17.4725	+0.0010	21×10^{-6}	0.057%
Soft Aluminum	23.3	10.2800	10.2823	+0.0023	100×10^{-6}	0.022%
Soft Aluminum	28.3	12.3243	12.3254	+0.0011	40×10^{-6}	0.005%
Hard Aluminum	28.9	6.2502	6.2528	+0.0026	90×10^{-6}	0.042%
Hard Aluminum	33.1	7.2228	7.2244	+0.0014	42×10^{-3}	0.020%

TABLE VII (CONTINUED)

Sample	Area, cm^2	$Weight_1$, g	$Weight_2$, g	$\Delta W(W_2-W_1)$	ΔW/Area	$\Delta W/W_1 \times 100$
Magnesium	41.5	5.7104	5.7178	+0.0074	178×10^{-6}	0.130%
Magnesium	40.1	5.8632	5.8840	+0.0208	518×10^{-6}	0.354%
Brass	25.4	15.6604	15.6634	+0.0029	114×10^{-6}	0.019%
Brass	24.4	15.3420	15.3434	+0.0014	57×10^{-6}	0.009%
Inconel	51.0	17.5156	17.5183	+0.0027	53×10^{-6}	0.021%
Inconel	51.0	17.5235	17.5250	+0.0015	30×10^{-6}	0.009%
316 Stainless	38.0	74.9970	74.9995	+0.0025	66×10^{-6}	0.003%
316 Stinless	42.9	84.7970	84.7992	+0.0022	51×10^{-6}	0.003%

$Weight_1$ is the weight of the sample prior to test
$Weight_2$ is the weight of the sample after the test

1. Vapor Pressures

Because of the difficulties in experimentally determining vapor pressures and because some aluminum alkyls decompose at temperatures approximating their boiling point, vapor pressures were calculated using Raoults Law and literature data. Table VIII gives the basis for estimating the vapor pressure of 90223-9.

TABLE VIII. CALCULATED VAPOR PRESSURE OF AGENT 90223-9

	TEA	Circosol 410	α-Methyl Naphthalene	Total
Empirical Formula	$C_6H_{15}Al$	--	$C_{11}H_{10}$	--
Molecular Weight	114.7	350 *	142.19	--
Composition, %	25	68	7	100
Moles/100 g	0.2180	0.1943	0.0492	--
Mole Fraction	0.4724	0.4210	0.1066	1.0000
Vapor Pressure, mm				
-40°F	<0.001	<0.0001	<0.001	--
77°F	0.030	~0.0001	0.056	--
140°F	0.788	~0.01	0.759	--
Partial Pressure, mm				
-40°F	immaterial	immaterial	immaterial	immaterial
77°F	immaterial	immaterial	immaterial	immaterial
140°F	0.38	immaterial	0.08	0.46

* Estimated

Source of V.P. Data: U. A. Lehikoinen and M. E. Gluckstein
Organometallic Screening Materials
Final Report to U. S. Army LWL

The calculations show that the vapor pressures for all agents are less than 1 mm.

2. SYSTEM DESIGN

a. Nozzle System

(1) Nozzle Type

Oil burner nozzles proved more effective than modified brass plugs. The nozzles produced a finely divided liquid spray rather than the liquid stream formed by brass plugs. Since this resulted in more intimate mixing with air and moisture, more oil was vaporized, creating a superior smoke.

(2) Nozzle Size

The selection of nozzle size was based on the desired dissemination time of 6-8 minutes, average working pressures (~125 psi), and disseminator capacity (1500 ml). A summary of the research in this area is given in Table IX.

(3) Number of Nozzles

Visual comparisons were used in evaluating the single-nozzle and tri-nozzle systems. We decided the tri-nozzle system produced a denser and more effective smoke.

b. Pressure Testing

The effects of pressure variation on dissemination time are shown in Table IX.

TABLE IX. EFFECT OF SYSTEM PARAMETERS ON DISSEMINATION TIME

Nozzle Number	Nozzle Size, GPH	Charge, ml	Pressure, psi	Dissemination Time, min.	Standardized Dissemination Time, min.
1	1.50	500	100	3.93	11.80
1	1.50	500	150	3.25	9.75
1	1.50	500	200	2.93	8.80
1	1.50	500	250	2.72	8.15
1	2.00	100	100	0.82	12.25
1	2.00	100	100	0.67	10.00
1	2.00	100	100	0.65	9.75
1	2.00	100	100	0.58	8.75
1	2.00	100	100	0.55	8.25
1	2.00	200	100	1.38	10.37
1	2.00	200	100	1.37	10.37
1	2.00	200	100	1.38	10.37
1	2.25	100	100	0.65	9.75
1	2.50	100	100	0.55	8.25
1	2.50	200	100	1.08	8.12
1	2.50	200	100	1.25	9.37
1	2.50	200	100	1.10	8.25
1	2.50	100	150	0.48	7.25
1	2.50	100	150	0.38	5.75
3	0.60	200	100	2.90	22.15
3	1.00	200	40	1.37	10.25
3	1.00	200	60	1.00	7.50
3	1.00	200	80	0.88	6.64
3	2.00	200	40	0.58	4.37
3	2.00	200	60	0.48	3.62
3	2.00	200	80	0.42	3.13

The standardized dissemination time is the time necessary to discharge a fully-loaded aluminum disseminator (1500 ml).

The effects of pressure on spray patterns was determined using 0.40 GPH Monarch nozzles and brass dispenser units. In eight separate runs, the pressure was gradually increased from 100 to 200 psi. In each case, it was found that the desired cone-shaped spray was not obtained until a pressure of 175-200 psi was reached. This indicated that, for a given nozzle size, a certain activating pressure must be reached before an effective spray results.

We also found that smoke generation is improved if the pressurizing gas is in direct contact with the smoke agent. This method was somewhat superior to indirect pressurizing by a physical object, such as the Bellofram diaphragm of the aluminum disseminators. Apparently, when under pressure, some of the expulsion gas dissolves in the liquid smoke agent. This dissolved gas serves to enhance particle break-up of the liquid upon dissemination through the nozzle orifice. Such break-up improves the smoke.

After examining these experimental results and visual comparisons of the smoke screens produced during each test, we decided to incorporate into the prototype disseminator a tri-nozzle system consisting of three 1.00 GPH, 60°R, solid-cone spray nozzles. At pressures obtainable with the pyrotechnic gas generator, smaller nozzles gave inferior sprays and, thus, less-effective smokes. Large nozzles produced an adequate smoke, but the dissemination time was much shorter than 10 minutes.

3. SMOKE GENERATOR

a. Unit Function and Pressure Curves

Disseminating a smoke simulant (consisting of 75% Circosol No. 410 oil and 25% kerosene mixture) resulted in the time pressure curves shown in Figure 4 as Test Nos. 1 and 2. This information enabled us to use metered nitrogen to apply controlled dissemination pressure to our test units for evaluation of smoke screens. These curves were obtained using a single 2.5 GPH, 60°R, solid spray nozzle.

Numerous tests indicated the single-nozzle approach was not producing the desired smoke pattern. A new design incorporated three 1.00 GPH, 60°R, solid spray nozzles.

The workhorse models were reworked to provide the additional nozzle mountings. The time-pressure curve shown in Figure 4, dated 20 December 1966, shows that the three-nozzle configurations had very little effect on the overall curve and length of the dissemination time. However, the smoke cloud was judged satisfactory for the application. The higher peak pressure was due to better sealing of gas at the primer plug.

The first two aluminum smoke disseminators were tested successfully with no apparent problems other than a minor bulging of the flat surface of the housing. The 205-psig peak pressure obtained as shown in Figure 4 (24 January 1967) came as a surprise. This pressure was approximately 50 percent greater than the earlier tests run in the workhorse unit. This performance is attributed to improved sealing at the primer plug and less

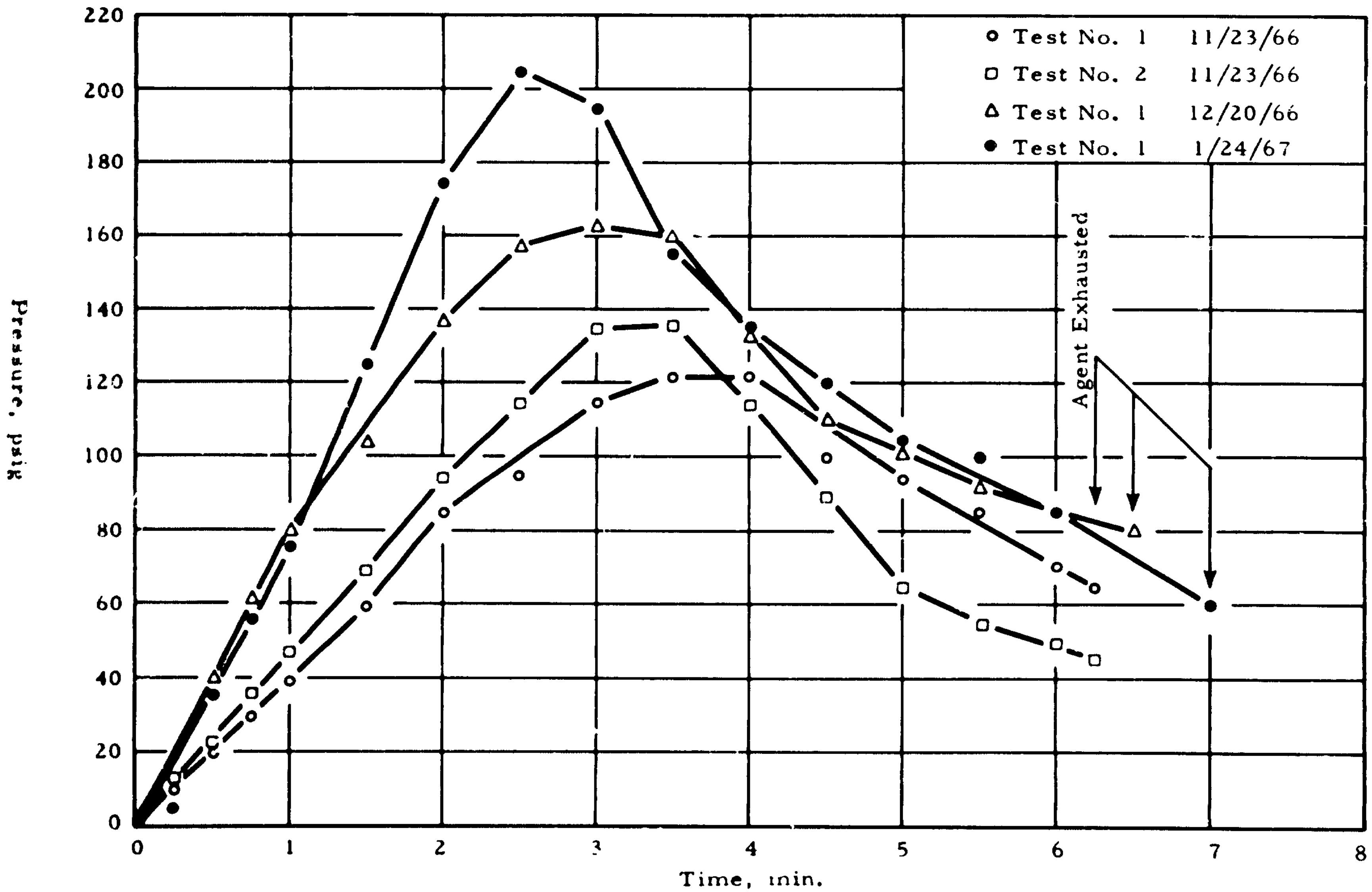


Figure 4. Time-Pressure Curves

heat loss in these units. This is due to the polyurethane insulation that encompasses the internal canister on all surfaces except the bottom.

Four more aluminum units were tested employing live agents with the conditions and results shown in Table X.

TABLE X. TESTS OF ALUMINUM SMOKE DISSEMINATORS

Test No.	Agent	Charge, ml	Nozzle	Position	Environment	Dissemination Time, min.
1	90223-7	1500	Three Delavan 1.00 GPH, 60°R, solid-cone spray	Vertical	Test stand	3-4 *
2	90223-7	1500	Three Delavan 1.00 GPH, 60°R, solid-cone spray	Vertical	Test stand	14
3	90223-9	1500	Three Delavan 1.00 GPH, 60°R, solid-cone spray	Horizontal	Water	7-1/2
4	90223-9	1500	Three Delavan 1.00 GPH, 60°R, solid-cone spray	Horizontal	Mud	7-3/4

* Unit ruptured before complete dissemination

We believe that Unit No. 1 contained a structural flaw that resulted in a weakened section. This section then ruptured as the peak pressure was approached. A more thorough discussion of similar phenomena is presented in the summary of large-scale field test results.

The third unit failed to float properly in shallow water. The nozzles were beneath the surface, causing an insufficient smoke screen. This demonstrated the need for at least two nozzles to be above the water surface during dissemination.

Because of this problem, studies were undertaken to further determine flotation characteristics when the units are charged with varying amounts of simulant. Figure 5 shows Unit Nos. 2, 4, 5, and 6 floating in a water rinse tank. Table XI shows the charge added and flotation results.

Figure 5. Flotation Studies

TABLE XI. FLOTATION RESULTS

Unit No.	Oil Wt., g	Total Wt., g	Results
6	None	1027	Unit floats on side with front edge 3-1/4 inch out of the water and the edge of the rear base 1-5/8 inch out of the water. One nozzle was underwater.
5	1382.1	2429.6	Nozzle end is up with closest nozzle 5/16 inch above the water. The unit is free-floating and is listing at approximately 6 degrees from the vertical.
4	700	1722	Unit is floating on side with all nozzles underwater. Front edge is 3/4 inch out of the water and the edge of the rear base is 2-1/4 inch out of the water.
2	700	1713	Rear base is submerged on all No.2 units. Lowest nozzle is 1/2 inch out of the water.
2	900	1913	Lowest nozzle is 9/16 inch out of the water.
2	600	1613	Lowest nozzle is 1/2 inch out of the water.
2	402	1415	Lowest nozzle is 3/8 inch out of the water.
2	203	1216	Lowest nozzle is 1/2 inch out of the water.

The units in Table XI (except the No. 2 units) represent the present design. Unit No. 6 was an empty unit, and it demonstrated the position in water at the end of the agent expulsion. Unit No. 5 was fully loaded (actually 57 grams overweight). This showed that the units are free-floating and will correctly orient themselves in water. Unit No. 4 shows the smoke generator approximately one-half discharged with the Bellofram in mid-travel position. This means the unit is now nose-heavy and the nozzles are underwater.

This last condition is probably the worst we could have chosen. A self-functioning unit may not heel over so far, because the Bellofram is unrestricted and may take a different shape. This would move the momentary center-of-gravity some distance to the rear.

Unit No. 2 is a modification of the present units. In this unit, three flexible tubes, leading to the nozzles, were substituted for the Bellofram diaphragm. The tubes have weighted intake heads that seek the lowest point of the unit after it comes to rest. This design became feasible when compatibility tests showed that there was no reaction between the gases from the pressure generator and the smoke agents. Table X represents the probable orientation of such a modified unit during various stages of dissemination. Figure 5 shows that the unit, when half full of simulant, exhibits improved orientation when compared to the present units.

b. Hydrostatic Tests

Two units were subjected to hydrostatic testing until they failed at 320 and 300 psig, respectively. In each unit, the point of failure occurred at the center joint where the Bellofram is trapped between the flanges of the top cup and bottom housing. The 300-psig pressure seemed to provide an adequate safety factor for these units.

c. Drop Tests

Preparations for the drop tests are summarized in Table XII.

TABLE XII. 40-FOOT DROP TESTS

Unit	Empty Wt., g	Load Wt., g	Loaded Wt.,*g	3 Vanes	Drop Position
1	1025.9	1209.7	2235.6	Short	Nose Down
2	1010.0	1215.8	2225.8	None	Nose 45°
3	1003.0	1220.6	2223.6	None	Base Down
4	1019.2	1212.1	2231.3	None	Base 45°

* Approximate gross weight 4.94 lbs.

After dropping Unit Nos. 1 through 4, the following damage was noted:

Unit No.	Orientation at Impact	Drop Test Results Visible Damage
1	Hit about 25° off vertical axis	Dented outside sleeve and nose cup
2	Hit about 40° off vertical axis	Dented outside sleeve and nose cup Minor leakage at one nozzle
3	Hit about 25° off vertical axis	Bent pusher plate in one area
4	Hit about 40° off vertical axis	Bent pusher plate in one area, causing slight gas leak at bottom screw

Figure 6 shows the record of mechanical damage.

Unit Nos. 1 through 4 were taped together after drop tests in such a manner that they could all be fired simultaneously. One unit failed because of primer malfunction; the primer was replaced, and the unit functioned normally on the next test.

d. Ejection from SUU-13/A

Data of unit preparation include:

Unit No.	Tare Wt., g	Charge Wt., g	Vane Length, in.	Ejector Tube No.
5	1026.6	1217.5	19	T1
6	1026.7	1217.5	19	T2

Figure 6. Results of 40-Foot Drop Test

Conditions and test results are summarized in Table XII.

TABLE XII. EJECTION TESTS

Unit No.	Wind Velocity, mph	Wind Direction, deg.	Firing Direction, deg.	Elevation, deg.	Range, ft.	Velocity, ft/sec.
5	24	295	270	45	138	N/A
6	21	300	270	45	150	96.7

The following recordings and observations were made during the tests.

1. Unit No. 5 (T1) landed on its side on muddy turf and functioned normally. The only physical damage noted was the vanes broken at the rear bend.

2. Unit No. 6 (T2) landed on its side in mud among a collection of brush, sticks, leaves, and grass. It functioned normally. The only physical damage was the three vanes broken off at the rear bend. Figure 7 shows the physical appearance of Unit Nos. 5 and 6 after ejection tests.

3. Although Unit No. 5 (T1) was 1/3-diameter deep in the muddy turf, it disseminated its cargo in approximately 6-1/2 minutes.

4. Fastax movies of the No. 6 shot (T2) were taken to determine ejection velocity.

5. 16-mm color films were made.

e. Compatibility with Smoke Agents

Viton was not seriously affected by the storage tests with the diluents. It was still soft and flexible, with no indication of swelling or cracking. The surface was slightly discolored.

Replacement of the Bellofram diaphragm by flexible tubes proved feasible as the modified unit performed normally with these alterations. Expulsion gases did not appear to degrade the smoke, but may in fact enhanced it (see discussion of pressure testing).

f. Field Tests

Two field tests, simulating flight drop patterns obtainable with the SUU-13/A system, were conducted at Avco's test facilities at Connersville, Indiana. Photographic coverage included 16-mm color movies with two cameras. Twenty aluminum disseminators were used -- nine for each test and two spares. The units were filled with candidate agents 90223-7 and 90223-9. The weight of the smoke agent per unit varied from 2 lb-13 oz to 3 lb, as shown in Table XIV.

Figure 7.   Results of Ejection Tests

TABLE XIV. WEIGHT OF SMOKE AGENT PER UNIT

90223-7		90223-9	
Unit No.	Weight, lb-oz	Unit No.	Weight, lb-oz
1	2-15	11	2-14
2	2-14	12	2-14
3	2-15	13	2-14
4	2-14	14	2-14
5	2-14	15	2-14
6	2-15	16	2-15
7	2-13	17	2-15
8	2-13	18	2-15
9	2-14	19	2-15
10	2-15	20	3-0

Note: Units 1-4 were of earlier design and contained screw-in nozzles; units 5-20 contained staked-in nozzles. None contained a pusher plate.

The test field was arranged as in Figure 8. The units were placed on the corners of an equilateral triangle having 32-foot sides. Based on the intervalometer operating characteristics of the present SUU-13/A dispenser, the probable minimum distance between canisters is 32 feet at 600 KIAS. Three of the units were placed in an upright position, with the remainder positioned horizontally. There were two rows of markers, the first six of each row set 5 feet apart and the remainder at 10-foot intervals. Photographic coverage included films, slides, and stills.

The first test was conducted using smoke agent 90223-7. The tape protecting the nozzle's orifice was removed, and the units were actuated simultaneously. Units in positions I, III, V, VI, and IX started to smoke about the orifice upon removal of the tape. Units II and III failed to operate due to a fault in the actuating mechanism. No. II was replaced by a spare, while the fault in No. III was corrected. The No. 1 unit ruptured shortly after dissemination began, and the unit in No. III position also blew apart about two minutes later. At the time of rupture, both units appeared to be functioning correctly, with no visual evidence of nozzle plugging. After the run was completed, the two units were examined. Both appeared to have separated initially at the center joint where the Bellofram diaphragm is crimped in place. These were two of the four units with screwed-in nozzles. Unit XIII contained residual agent. There was no evidence of internal pressure upon removal of the nut closing the loading port on that unit.

The units, collectively and individually, produced fairly dense white smoke screens. The individual screens did not become coherent until they merged in an area beyond the second row of markers. Maximum height was about 20 feet. Readings of wind direction and velocity were begun at the start of dissemination, repeated at 30-second intervals, and discontinued after completion of smoke generation. The wind velocities are shown in Table XV.

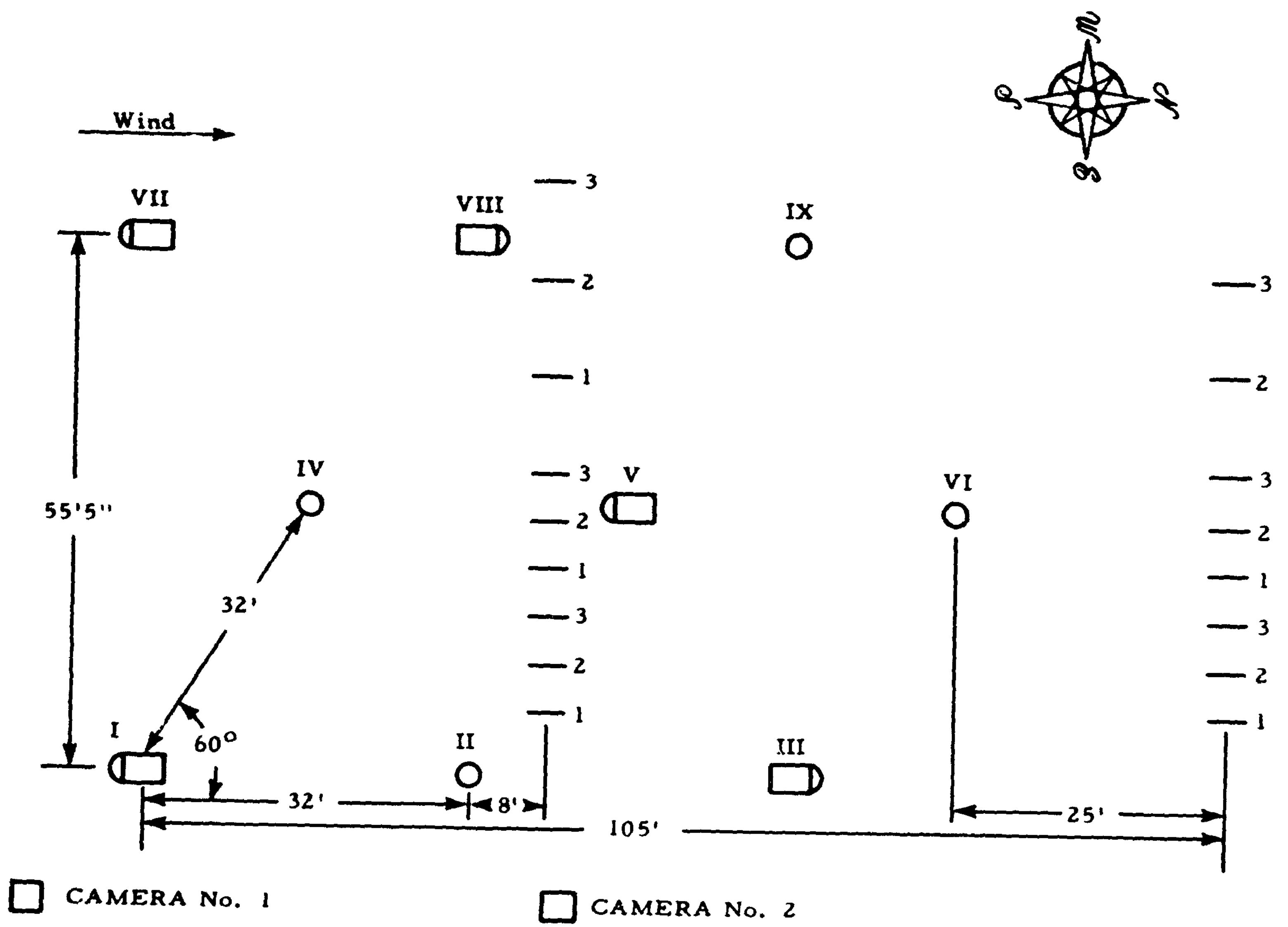


Figure 8. Deployment of Disseminators on Test Field

TABLE XV. WIND DIRECTION AND VELOCITY DURING FIELD TESTING OF 90223-7

Time, min.	Direction, deg.	Velocity, mph	Time, min.	Direction, deg.	Velocity, mph
0	180	8	5	190	7
0.5	170	7	5.5	200	5
1	180	8	6	180	4
1.5	185	11	6.5	195	4
2	195	11	7	180	5
2.5	180	11	7.5	170	7
3	170	9	8	180	12
3.5	180	8	8.5	180	16
4	170	13	9	170	15
4.5	180	11			

The second run, using agent 90223-9, was conducted according to the same procedure. Field unit No. II exploded approximately three minutes after starting dissemination. It also appeared to have ruptured at the center joint. All of the remaining units functioned well, producing a dense, cohesive, white smoke. It was noted that this screen was higher than the first. It also appeared, as found in other tests, that the smoke rises at low velocities (0-4 mph) and tends to remain lower at higher velocities (7 mph or higher). Consequently, the placement and height of the markers were not an effective means of measuring the obscuration of these screens. The screen was considerably higher and denser than the one from the first run because of lower wind velocity, as shown in Table XVI.

TABLE XVI. WIND DIRECTION AND VELOCITY DURING FIELD TESTING OF 90223-9

Time, min.	Direction, deg.	Velocity, mph	Time, min.	Direction, deg.	Velocity, mph
0	210	14	4	215	6
0.5	200	14	4.5	205	5
1	180	13	5	200	5
1.5	185	9	5.5	210	5
2	200	12	6	215	4
2.5	195	7	6.5	190	4
3	200	8	7	210	5
3.5	200	11			

The units that malfunctioned during the tests can be categorized into two groups as follows:

1. Primer malfunction
2. Mechanical failure at the center joint

Those units that failed to fire can be subdivided by cause as follows:

1. Insensitive primer that fired when firing hammer was tripped the second time.

2. Primer failure due to inadequate support of primer bridge by the holder. A new primer and holder assembly restored the unit to a usable item.

Those units that came apart during function can be grouped as follows:

1. Insufficient length of the rolled flange, which permitted bottom housing flange to escape. This was remedied on later units by making the flange longer.

2. Flange deformed on an angle, causing undue stress at the rim. This resulted in a sheared rim.

3. Metal failure at the rolled rim caused by invisible cracks in the metal due to the rolling operation.

The above problems can be overcome with tools that form a curled flange to replace the rolled flange. This will result in more uniform assemblied.

Production units fabricated by deep drawing methods in place of the spinning would have thicker walls (from the same basic stock thickness) and should withstand approximately 450 psig before failure. In this case, the 0.050-inch stock was reduced to approximately 0.031 inch at the points where these units failed. Spun parts can be developed to give full stock thickness, but it takes many times the total number of parts produced on this contract to reach this point of perfection.

4. AGENT CHARACTERIZATION

Based on the various evaluation techniques, agents 90223-7 and 90223-9 seemed to be the best screening materials. A summary of their properties is presented in Table XVII.

TABLE XVII. PROPERTIES OF CANDIDATE AGENTS 90223-7 AND 90223-9

Parameter	Unit	90223-7	90223-9
TEA	wt %	-	25
TEA-DEAH	wt %	25	-
α-Methylnaphthalene	wt %	7	7
Circosol 410 oil	wt %	68	68
MSN	-	31.8	30.5
VSN	-	16.4	15.8
TOP, fresh agent	sq ft/lb	612	565
TOP, 90 days at -40°F	sq ft/lb	624	504
TOP, 90 days at ambient	sq ft/lb	570	569
TOP, 90 days at 160°F	sq ft/lb	736	635
TOP, 6 hrs. at 212°F	sq ft/lb	572	525
Cloud point	°F	<-94	<-94
Pour point	+F	-72 ± 3	-62 ± 3
Fire point	°F	-62 ± 5	<-40
Viscosity, -35°F	centistokes	576	601
Viscosity, 83°F	centistokes	11.21	12.46
Viscosity, 16°F	centistokes	3.79	3.95
Vapor pressure, 140°F	mm	< 1	< 1
Density	g/ml	0.946 at -46°F	0.946 at -74°F
Density	g/ml	0.886 at 90°F	0.896 at 89°F
Density	g/ml	0.967 at 163°F	0.861 at 174°F

Corrosive effects of smoke:

Aluminum	None	None
316 Stainless Steel	None	None
Copper	None	None
Brass	None	None
Inconel	None	None
Magnesium	None	None
Irratability, 10-minute exposure	None	None
Toxicity	Probably none	Probably none

Antoine equation correlations were obtained from viscosity data:

90223-7

$\log \gamma + 1.02 = 537/t + 176$

γ = viscosity in cs

90223-9

$\log \gamma + 1.19 = 623/t + 188$

t = temperature in °F

5. SMOKE GENERATOR DESIGN

The smoke generating unit is a cylinder, 4-5/8 inches in diameter and approximately 9-3/4 inches long which weighs about 5 pounds. Figures 9 and 10 show a cross-sectional view and assembly of the smoke generator. Table XVIII lists the parts, number required, and their description. Figures 11-30 are details of the individual parts.

Structurally, the smoke generating unit consists of an inner two-piece canister separated from the outer cylinder by 0.25 inch of urethane foam, a pusher plate at the bottom end, and three divergent nozzles at the top end. The inner canister inside diameter is 4 inches, and the length is 9 inches. It contains approximately 98 cubic inches of smoke-producing agent. The bottom section of the canister, which is attached to the pusher plate, is debossed to accommodate the firing mechanism on the outside. A steel reinforcing plate, the barrier cup, and the pressure generator assembly are assembled in the bottom on the inside. The Bellofram (a flexible cup-shaped Viton rubber diaphragm) is clamped between the top and bottom section of the canister. The top end of the unit contains three 1.0 GPH, 60-degree, solid spray, commercial oil burner nozzles, modified to permit staking to the canister. The 1/4-inch polyurethane foam, which separates the canister from the outer cylinder, cushions the unit against severe impact loads and adds buoyancy to the unit, allowing it to function in water as well as on land. The pusher plate and associated parts provide additional weight at the bottom end to cause the unit to erect itself in water. Three steel ribbon vanes were attached to the top end to assure proper orientation in flight. Approximately three pounds of smoke agent is loaded into the unit through the filler plug at the top end.

Once the delay train has been actuated, expulsion gases are formed. As the pressure increases, the pusher plate is forced upwards against the Bellofram diaphragm. In turn, the agent contained between the diaphragm and inner canister walls is forced out through the nozzles, creating a fine spray that immediately forms a dense white smoke. This process continues until the diaphragm is completely inverted and all agent has been dispersed -- a period of about 6-8 minutes.

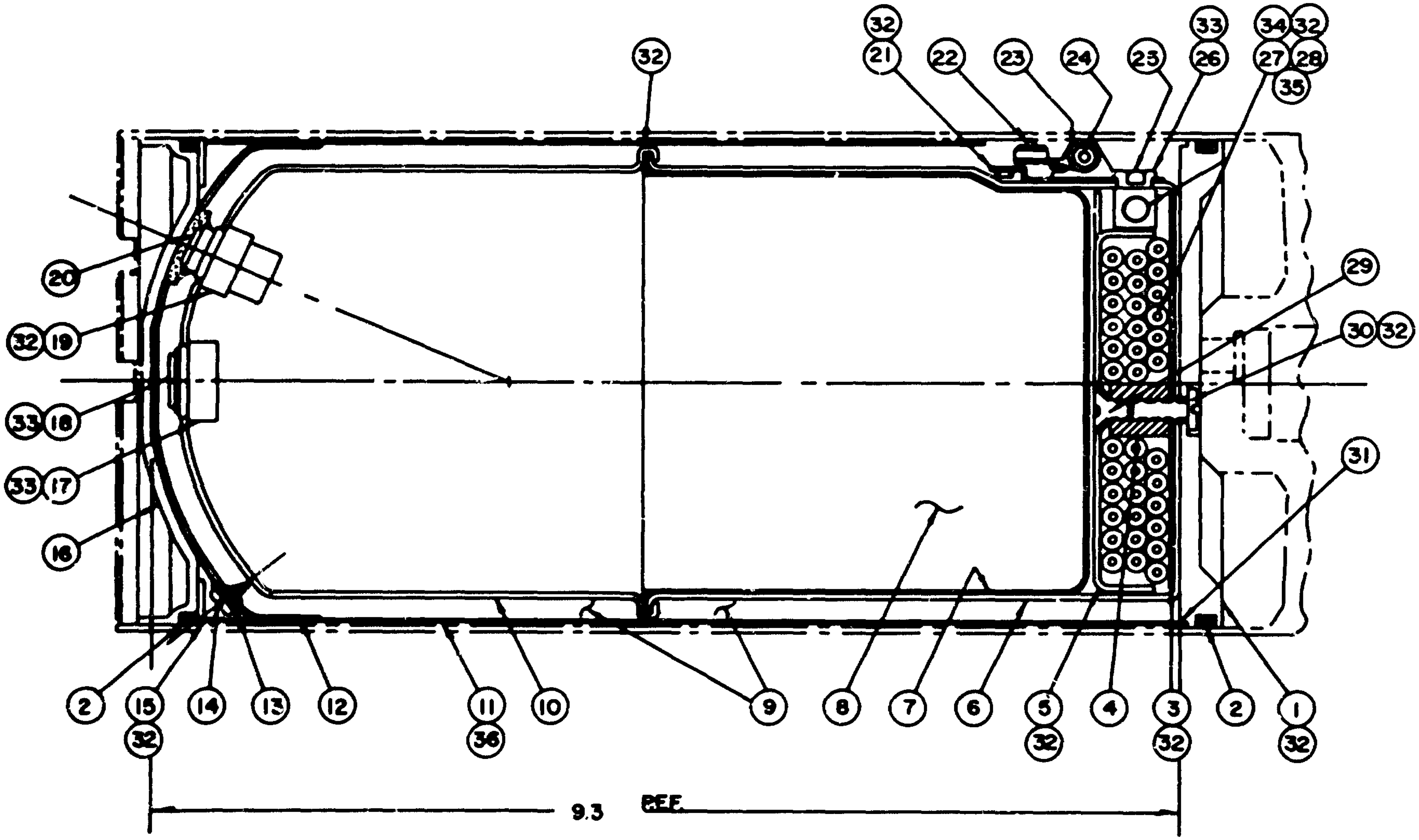


Figure 9. Smoke Generator-Cross-Section

TABLE XVIII. PART NUMBERS AND DESCRIPTION

ITEM No	No REQD	PART NUMBER	REV	DESCRIPTION
36	1	MS16535-112		RIVET 1/8" x 1/8" SEMI-TUBULAR
35	9'-11"			FUZE (SEE DWG. B2291-18)
34	X			3/4" WIDE MASKING TAPE
33	X			JOHN CRANE #2 PLASTIC LEAD SEAL
32	X	EC2216A & EC2216B		"3M" EPOXY CEMENT
31	1	D2291-12		SLEEVE
30	1	MS35223-63		#10-24 x 1/2 SLOTTED PAN HD. MACH. SCREW
29	1	MS35190-268		#10-24 x 5/16 C R FLT HD. MACH SCREW
28	1	B 2291-8	A	HOLDER (PART OF ITEM No. 27)
27	1	B 2291-18		PRESSURE GENERATOR ASSEMBLY
26	1	B 2291-9		PLUG
25	1	M-42		PRIMER
24	1	B 2291-15		PIN
23	1	B 2291-14		SPRING
22	1	B 13-10-13	H	GRENADE FUZE STRIKER ASSEMBLY
21	1	B 2291-7		BRACKET
20	3	B 2291-22		WASHER-SEALING
19	3	B 2291-1	A	NOZZLE-REVISED
18	1	MS 21336-		1/4" HEX. SOCKET PIPE PLUG
17	1	B 2291-10	A	BUSHING
16	1	C 2291-6		CUP-CLOSURE
15	1	B 2291-13		RING
14	3	MS 24642-22		#6 x 1/4 PAN HD. TYPE B THRD. FRM. SCREW
13	3	MS15795-206		WASHER-FLAT #6
12	1	C 2291-5		CUP-NOSE
11	1	B 2291-19		VANE ASSEMBLY
10	1	C 2291-4		CUP-TOP
9	X	B 2291-20		URETHANE FOAM
8		B 2291-21		SMOKE AGENT
7	1	4-400-400 (D-V)		BELLOFRAM
6	1	C 2291-3	A	HOUSING-BOTTOM
5	1	C 2291-2		CUP-BARRIER
4	1	B 2291-17		SPACER
3	1	B 2291-16		PLATE
2	2	MS 28775-245		"O" RING (4 3/8" x 4 5/8" x 1/8")
1	1	C2291-11		PLATE-PUSHER

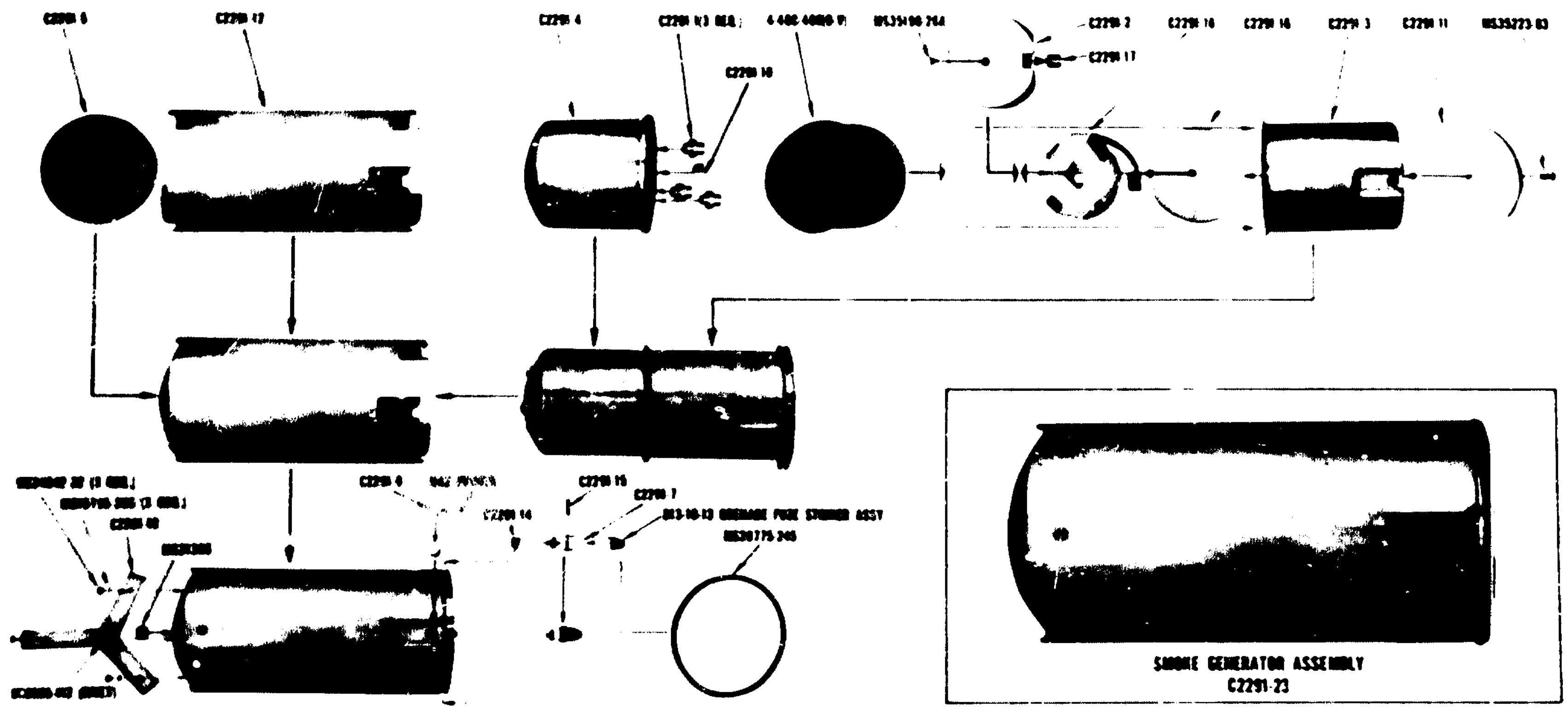


Figure 10. Smoke Generator Assembly

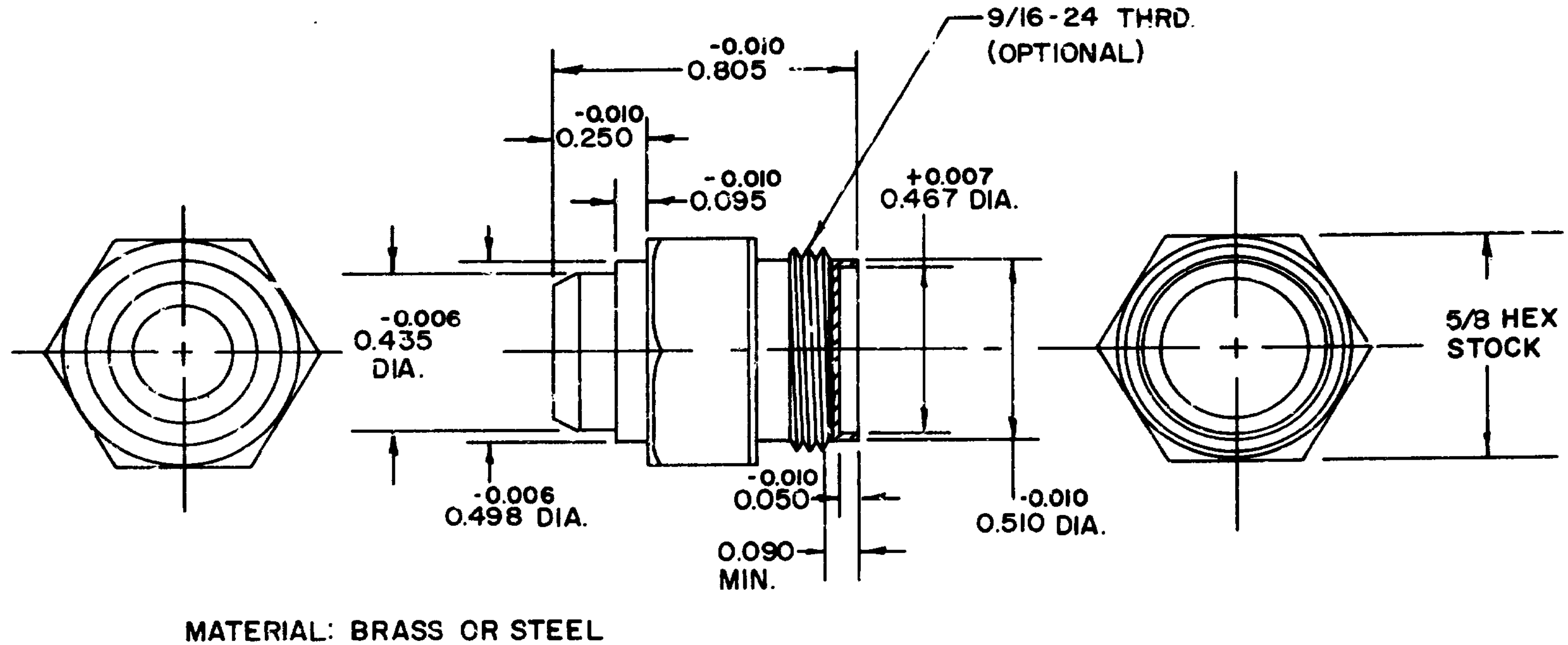


Figure 11. Nozzle-Revised

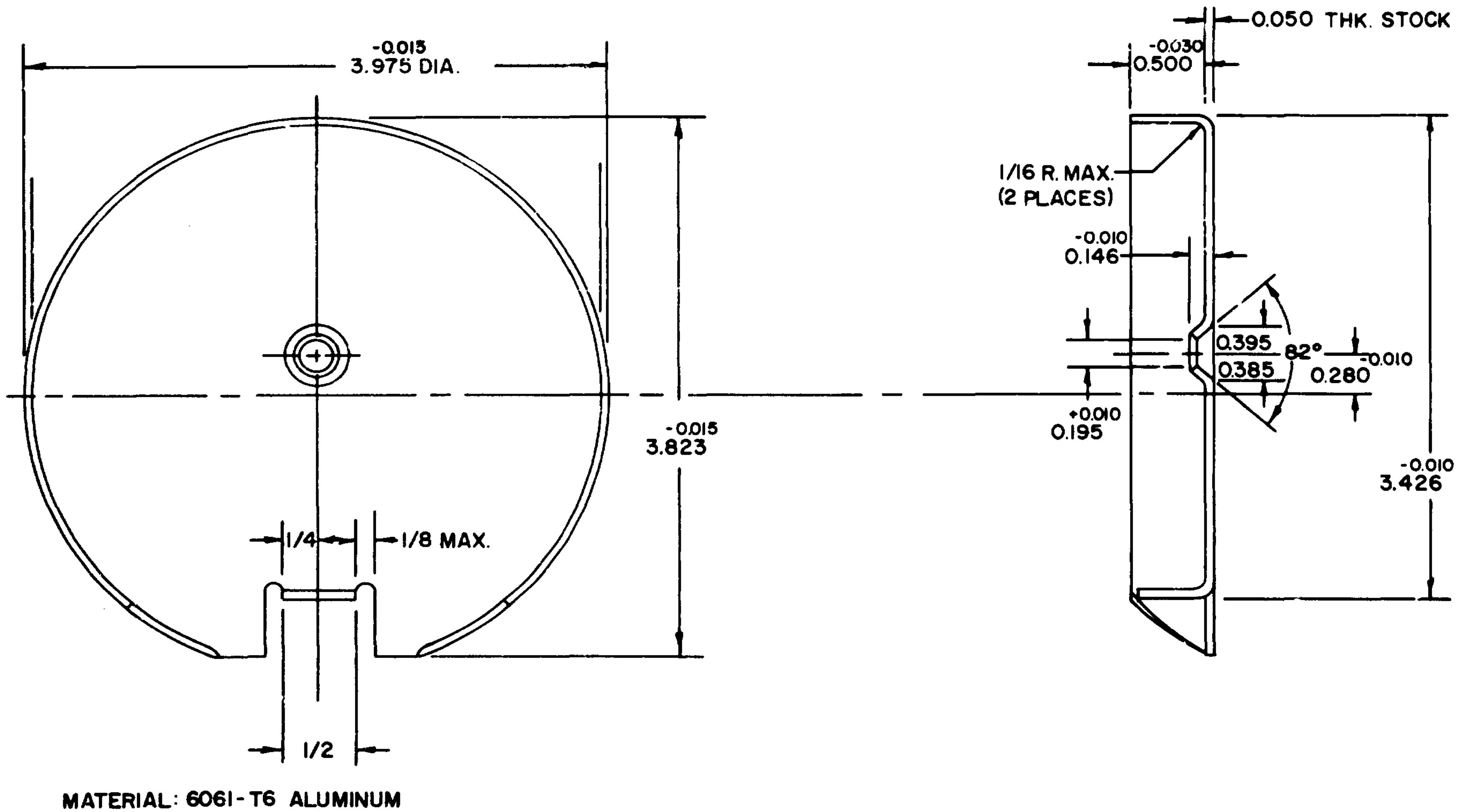
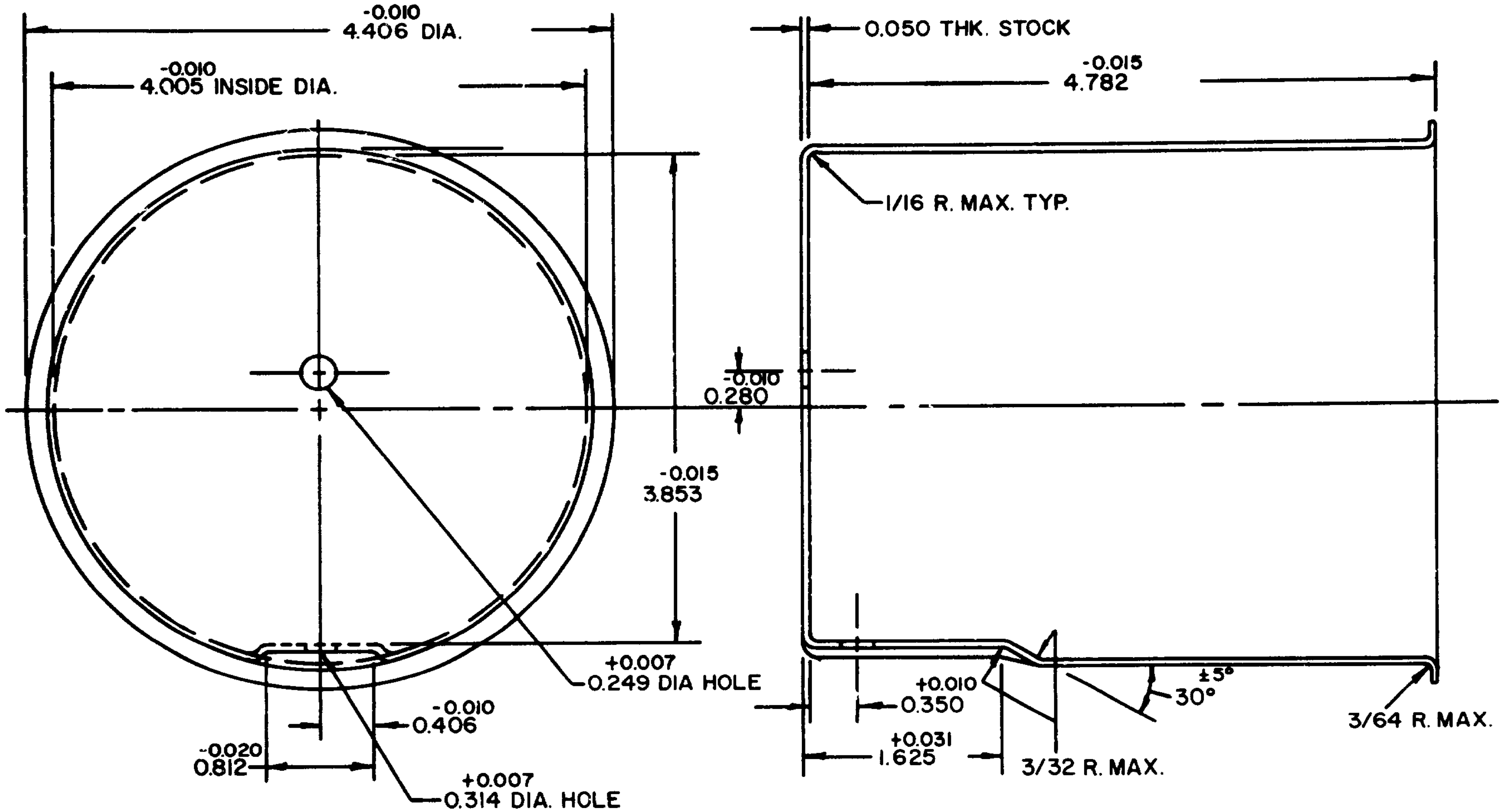


Figure 12. Cup-Barrier



MATERIAL: 6061-T6 ALUMINUM

Figure 13. Housing-Bottom

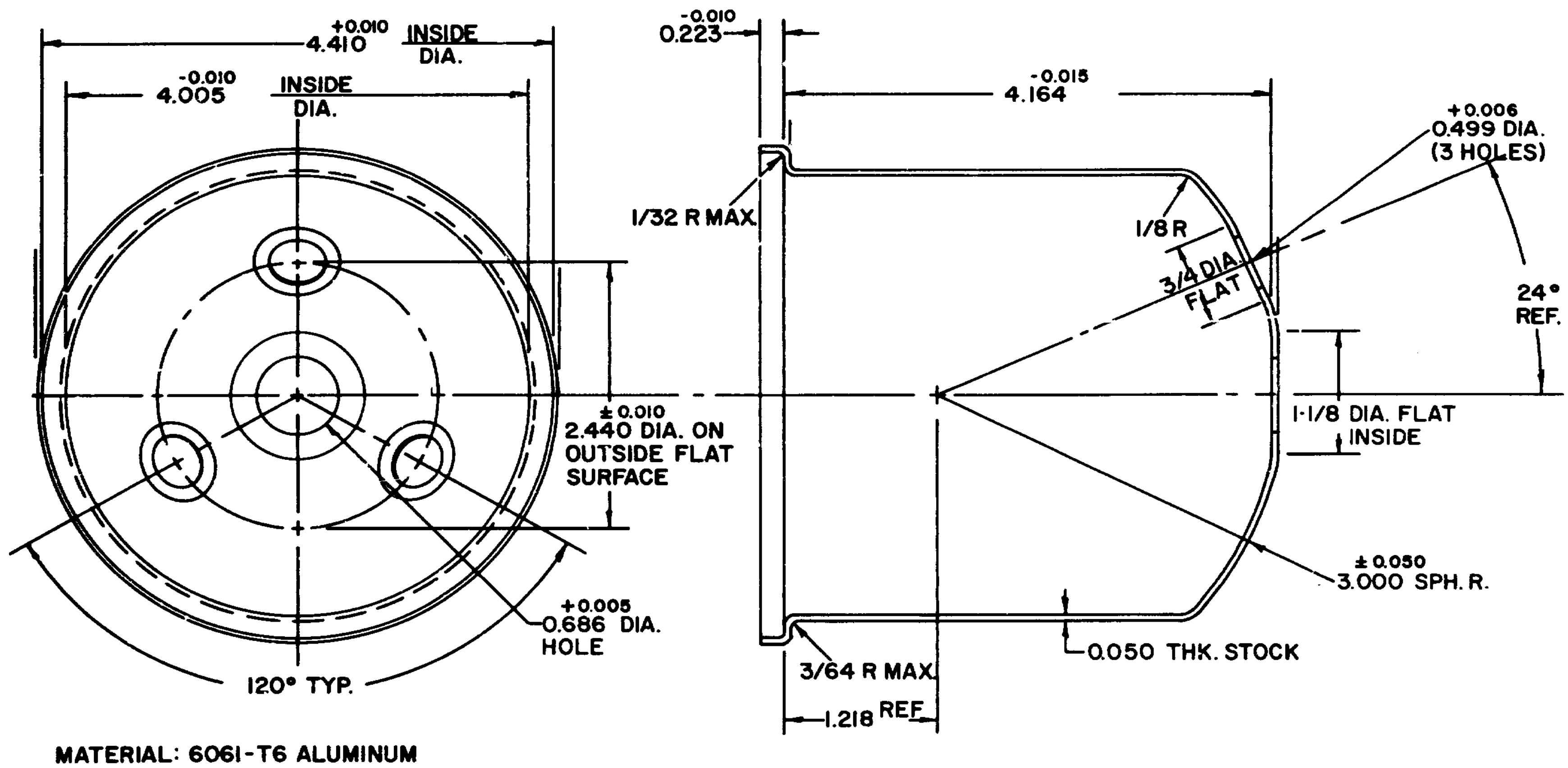


Figure 14. Cup-Top

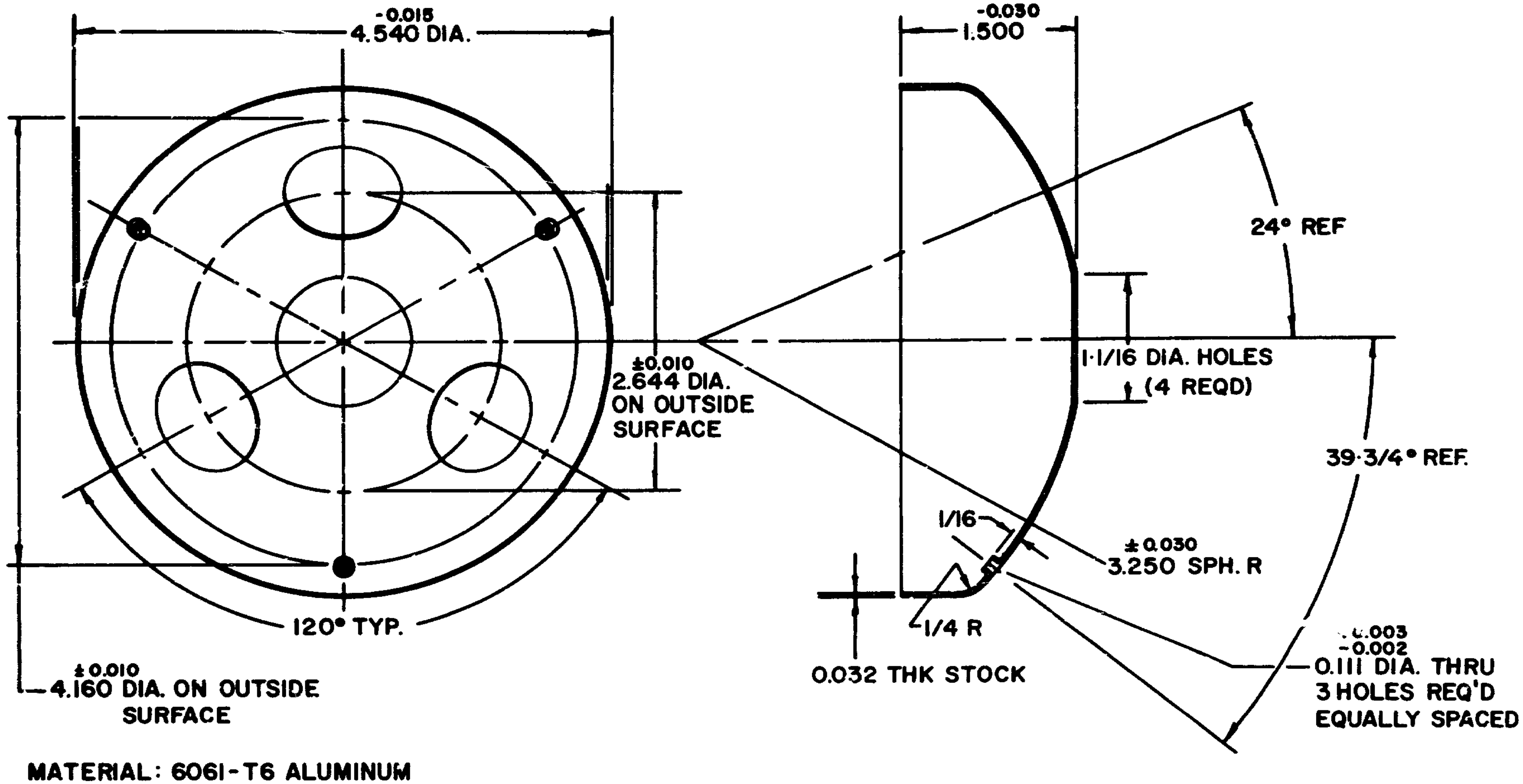


Figure 15. Cup-Nose

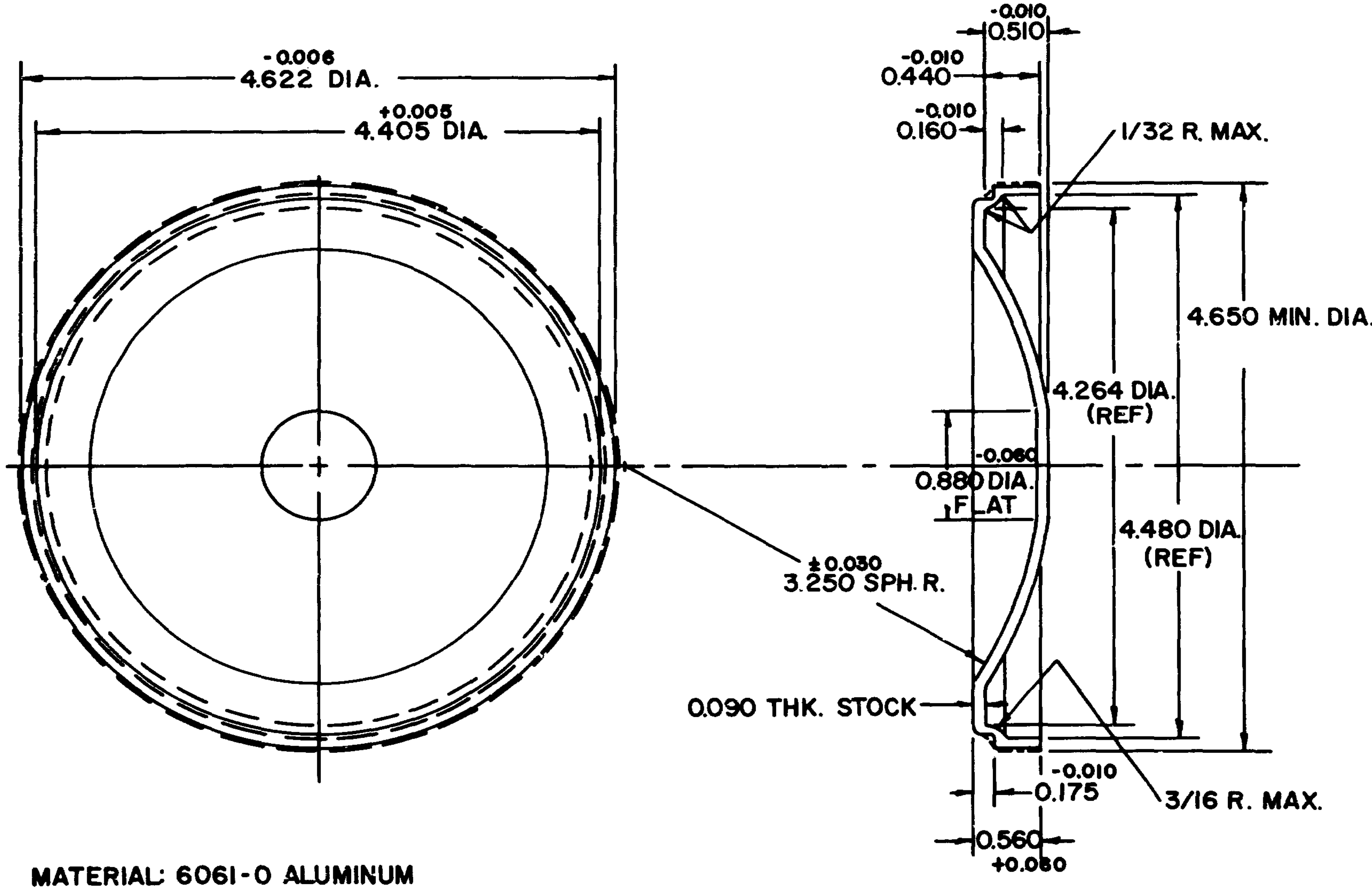


Figure 16. Cup-Closure

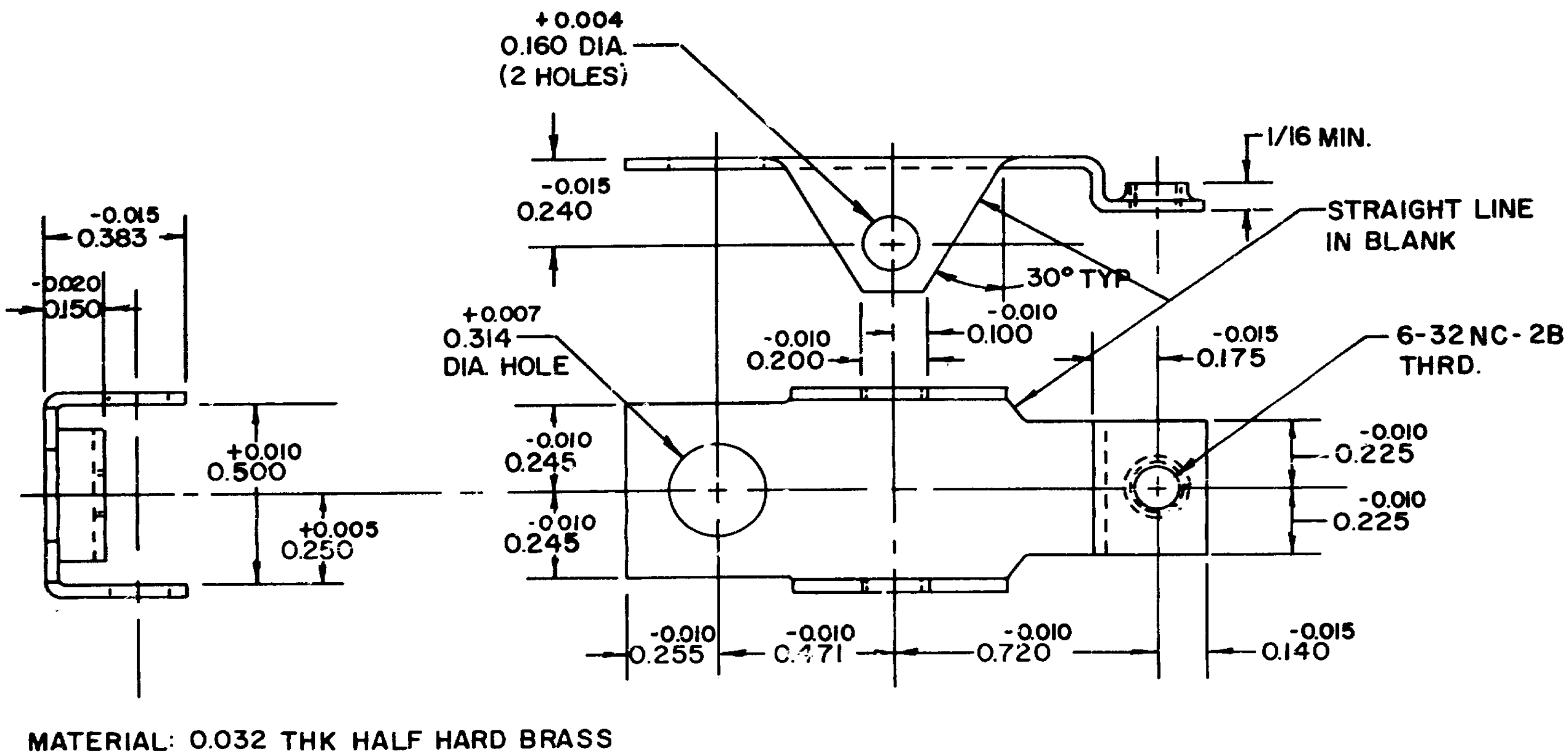


Figure 17. Bracket

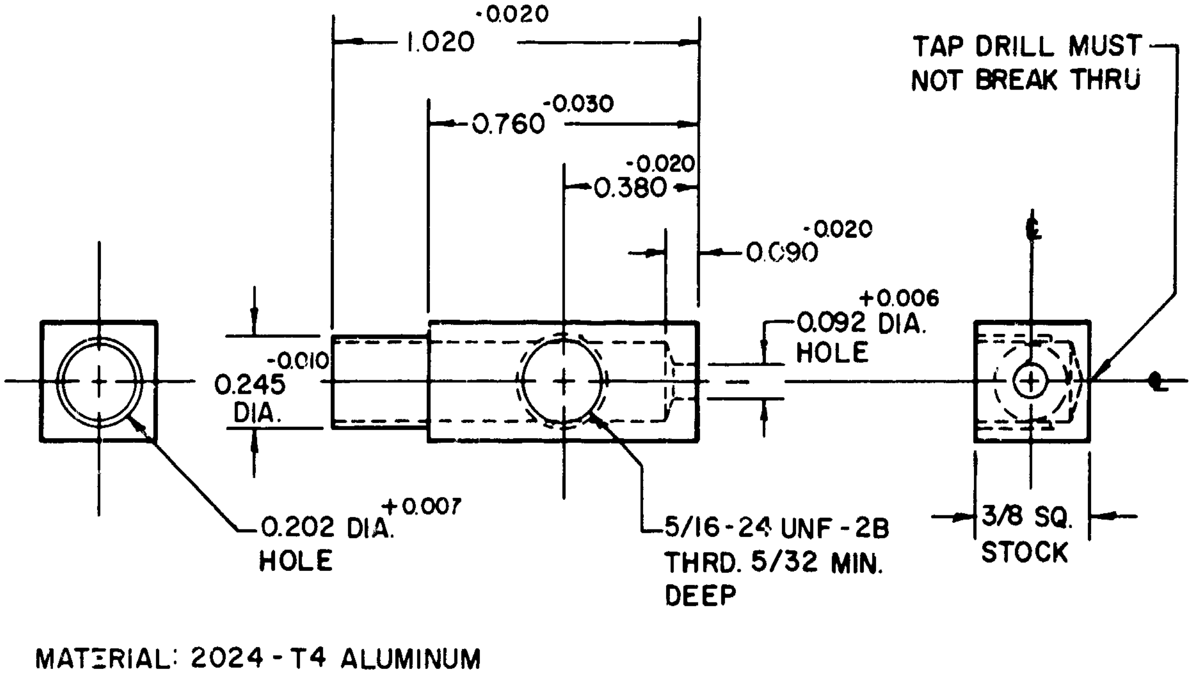


Figure 18. Holder

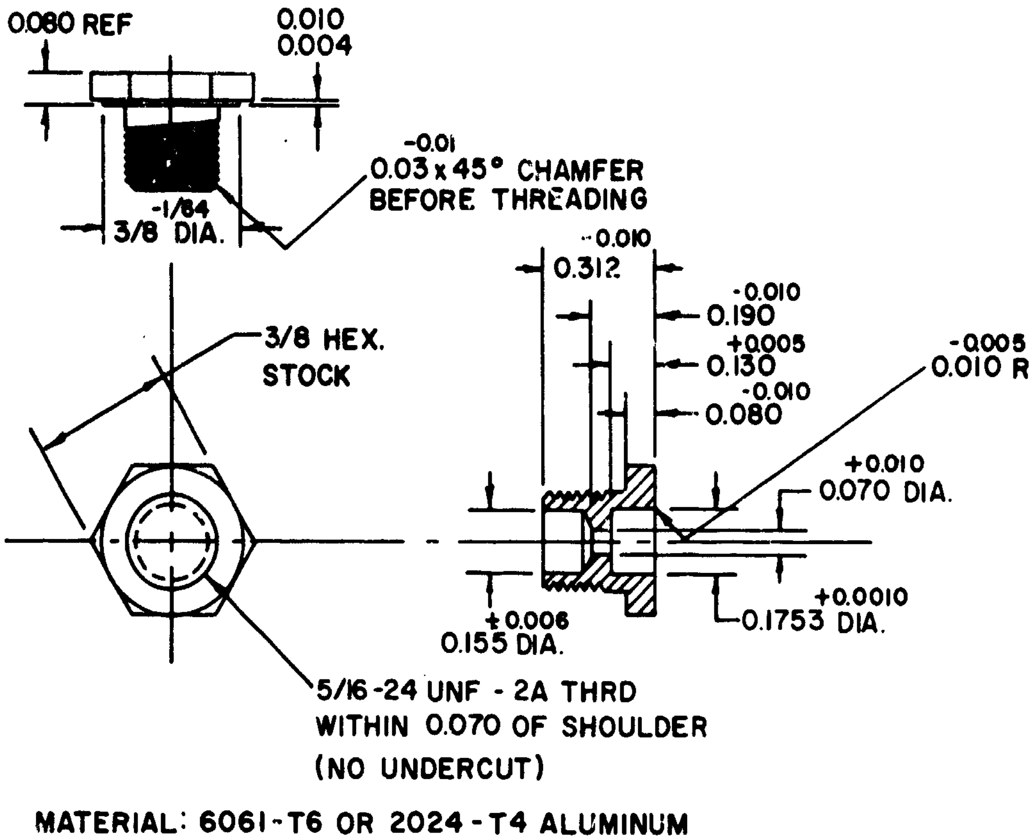


Figure 19. Plug

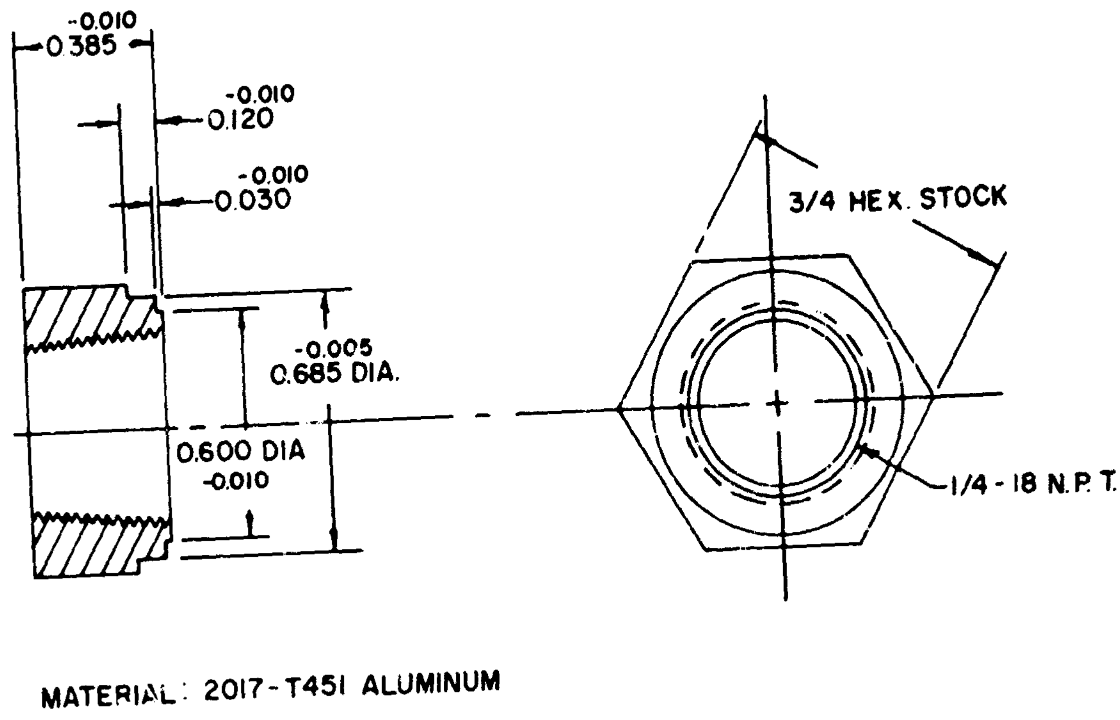


Figure 20. Bushing

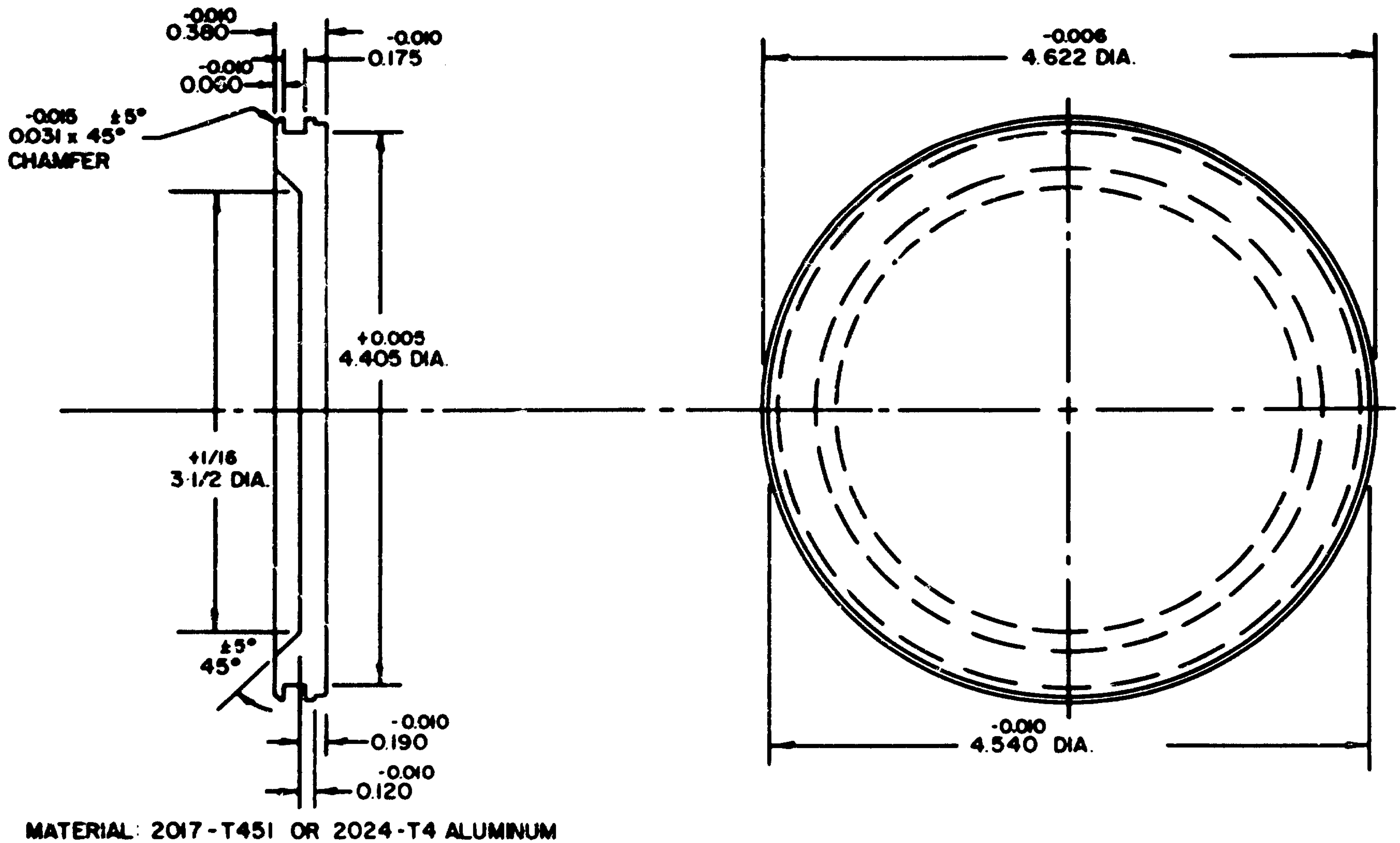


Figure 21. Plate-Pusher

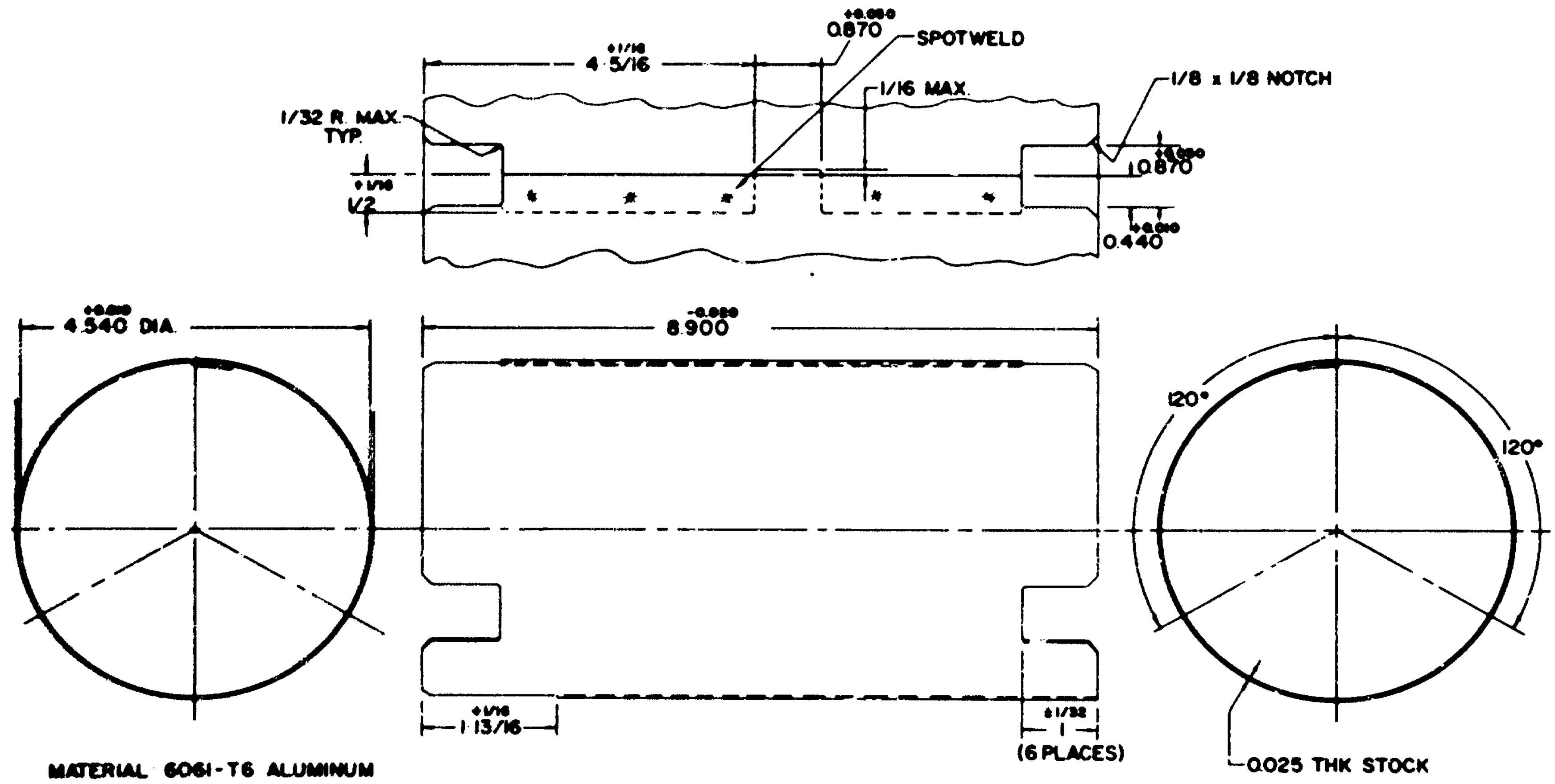


Figure 22. Sleeve

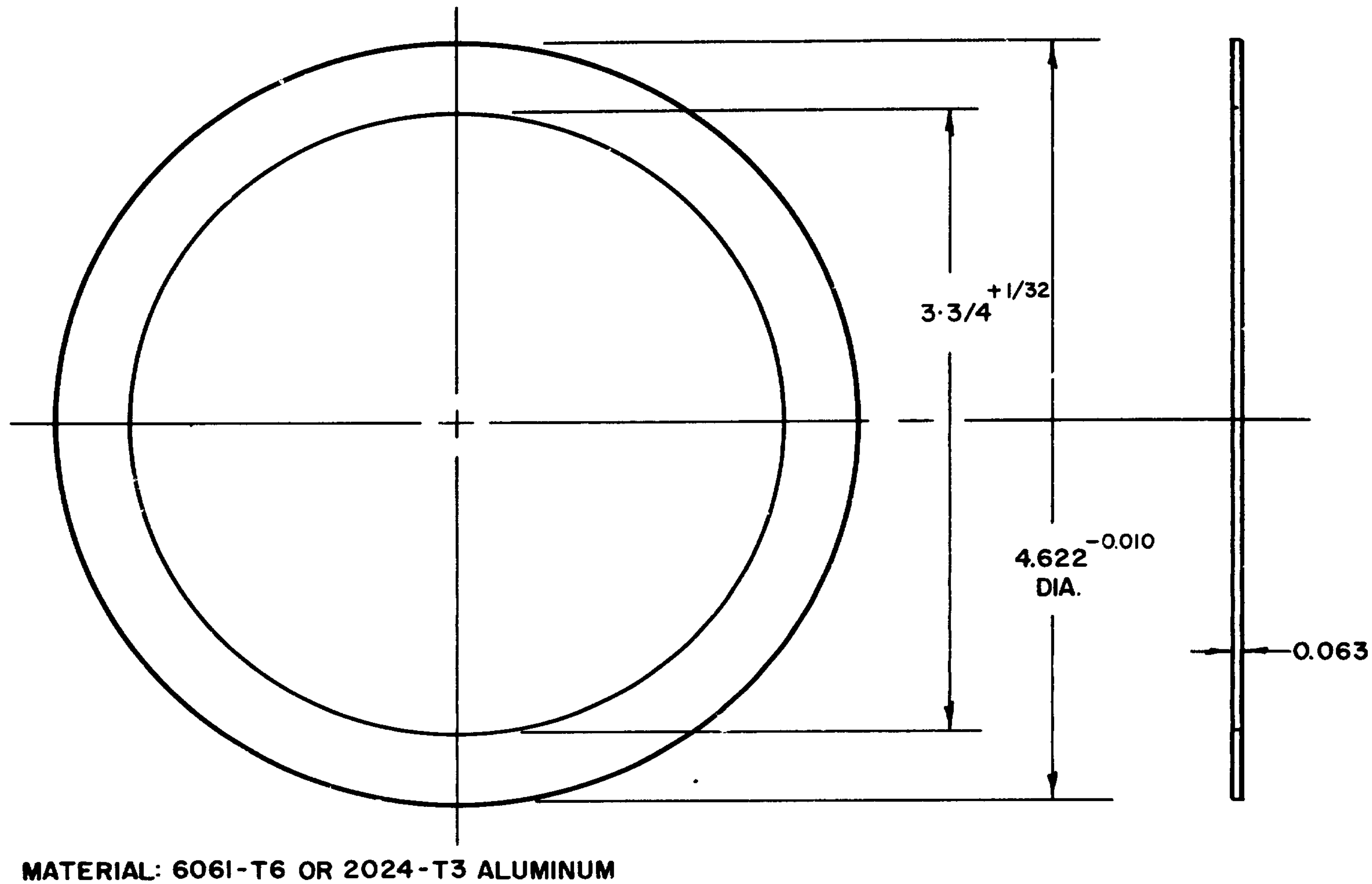


Figure 23. Ring

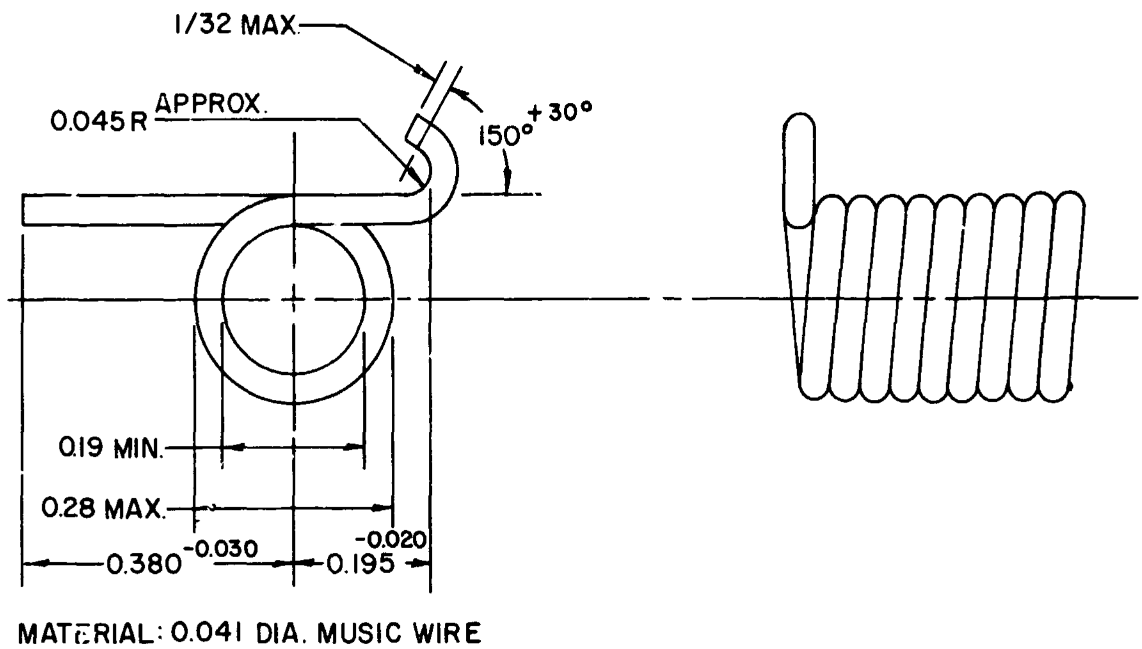


Figure 24. Spring

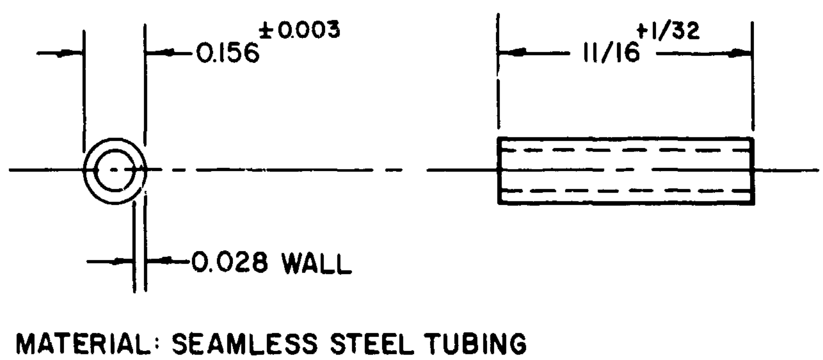
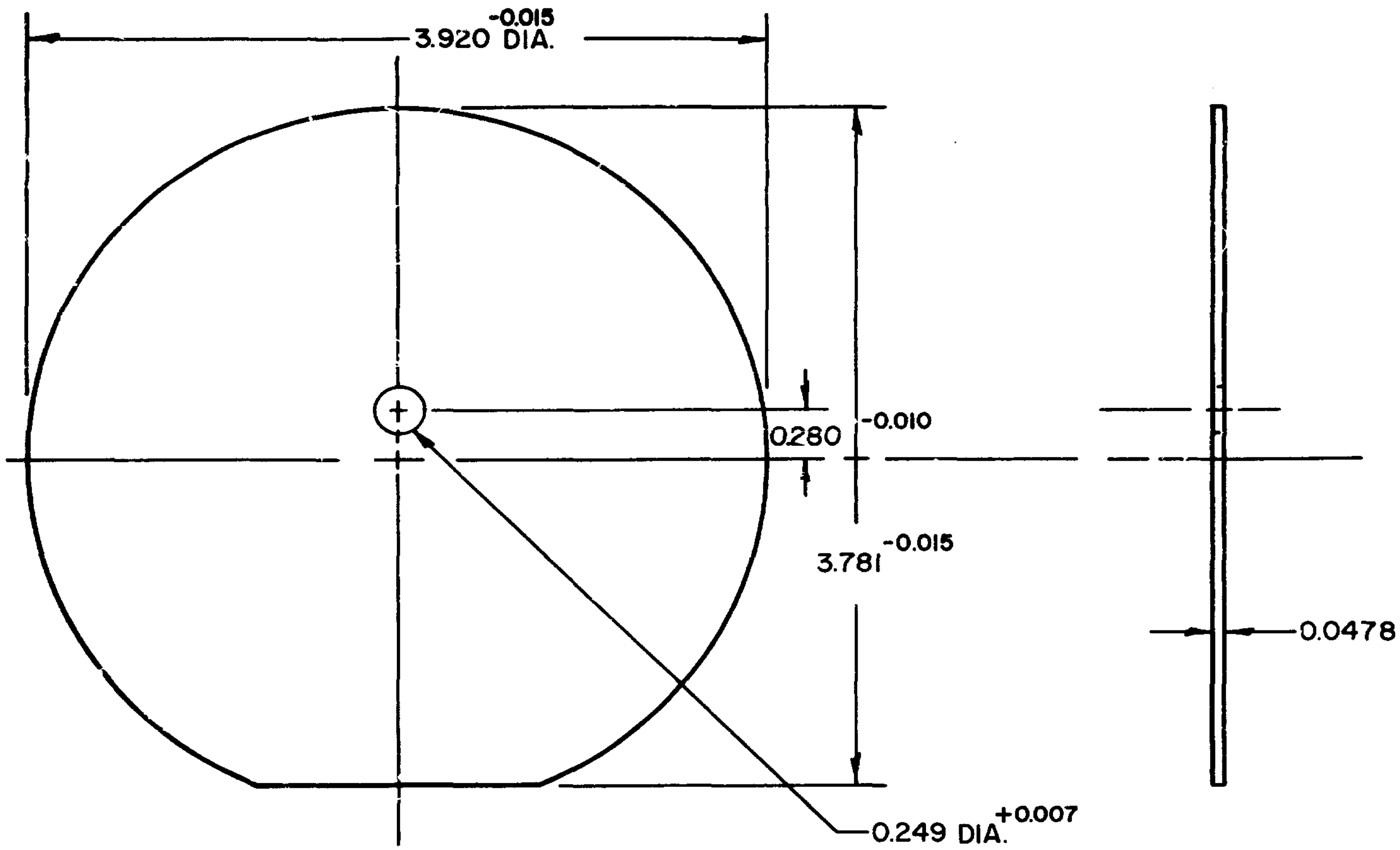


Figure 25. Pin



MATERIAL: COLD ROLLED STEEL

Figure 26. Plate

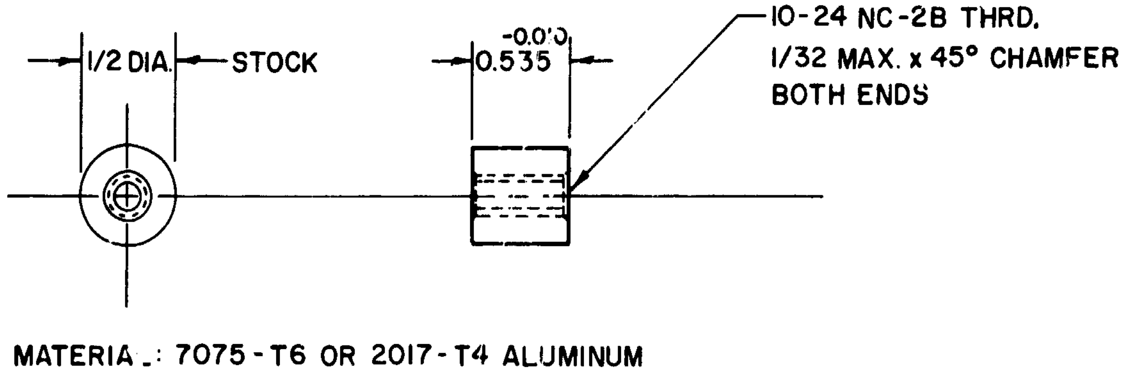


Figure 27. Spacer

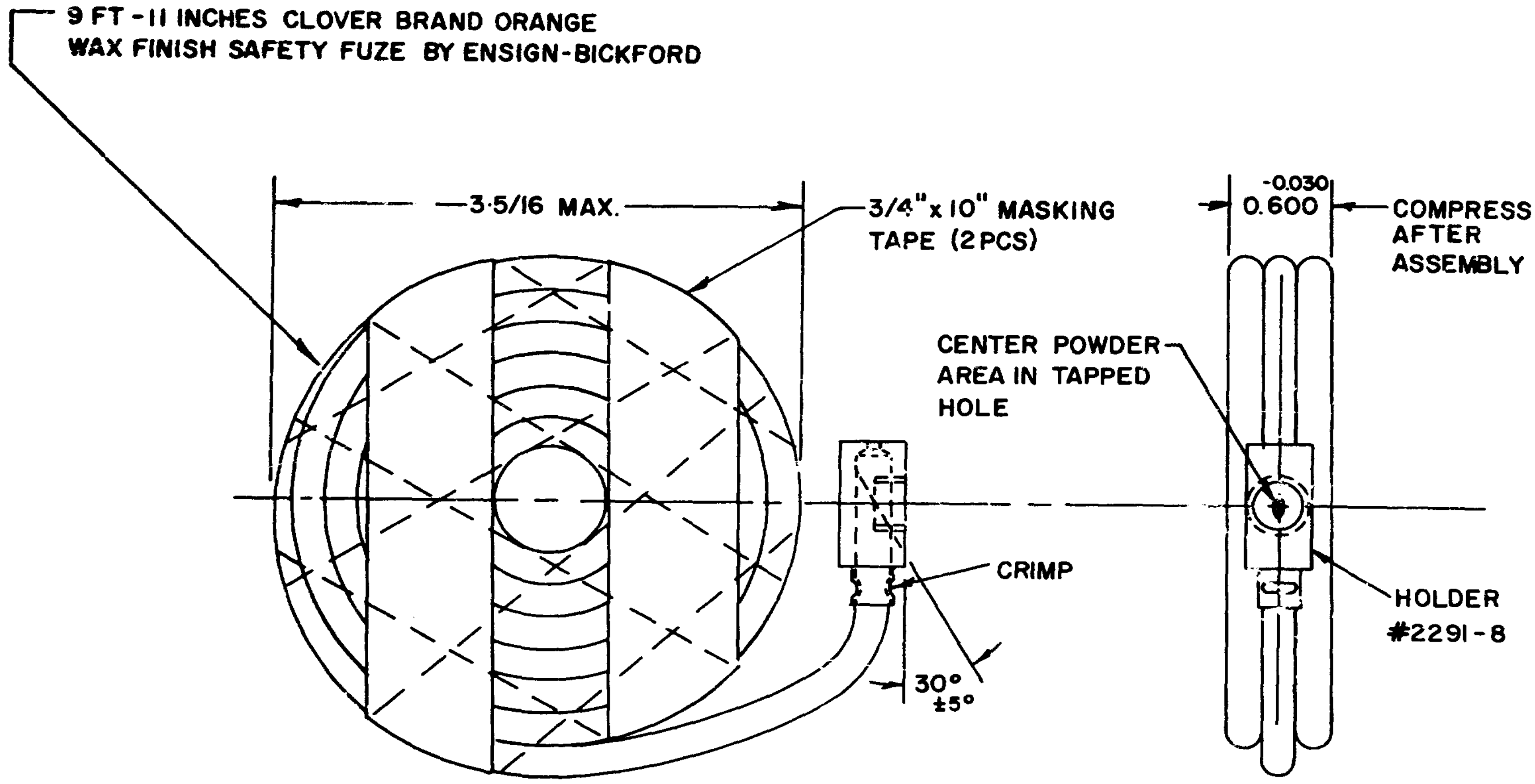


Figure 28. Pressure Generator Assembly

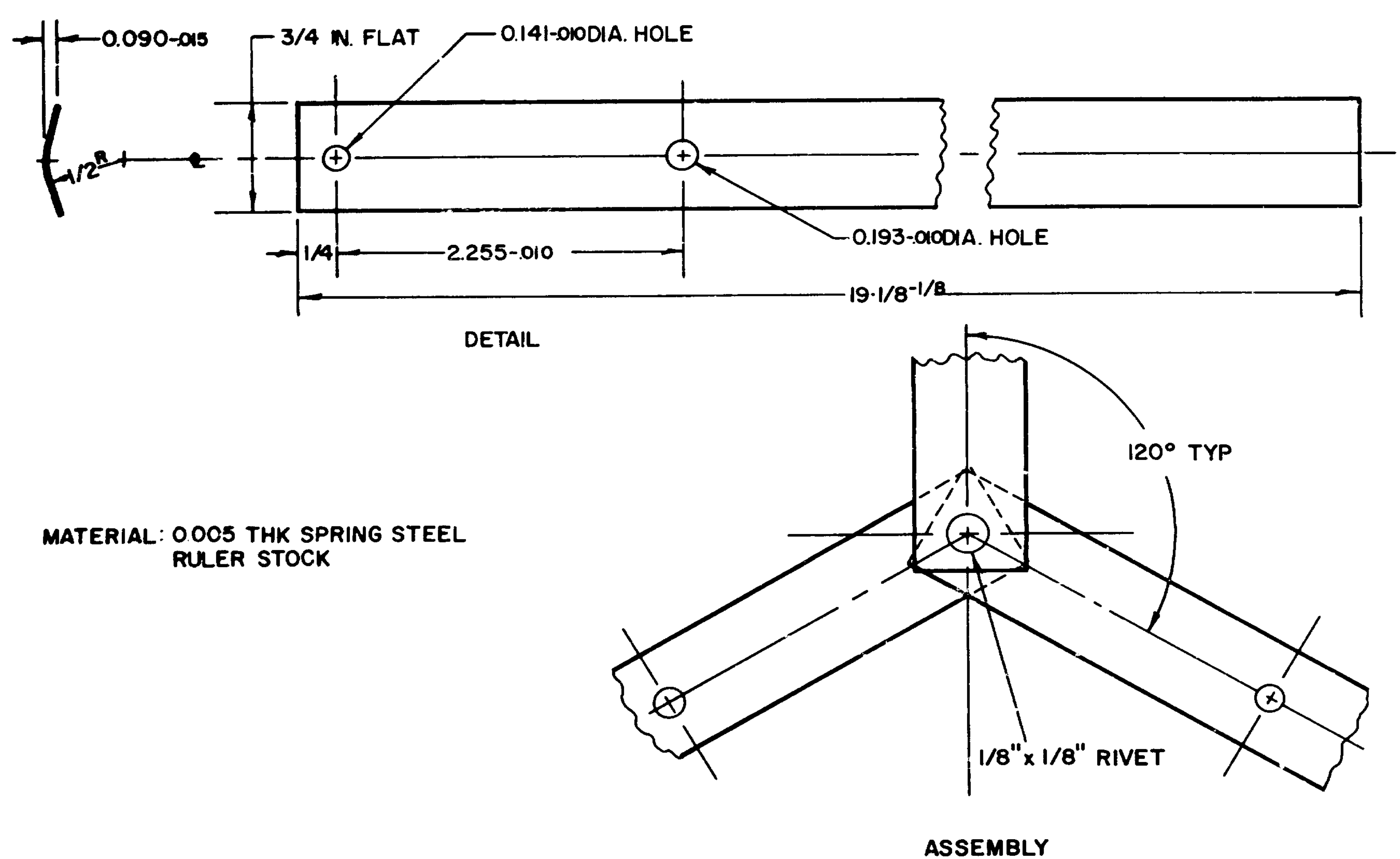


Figure 29. Vane Assembly

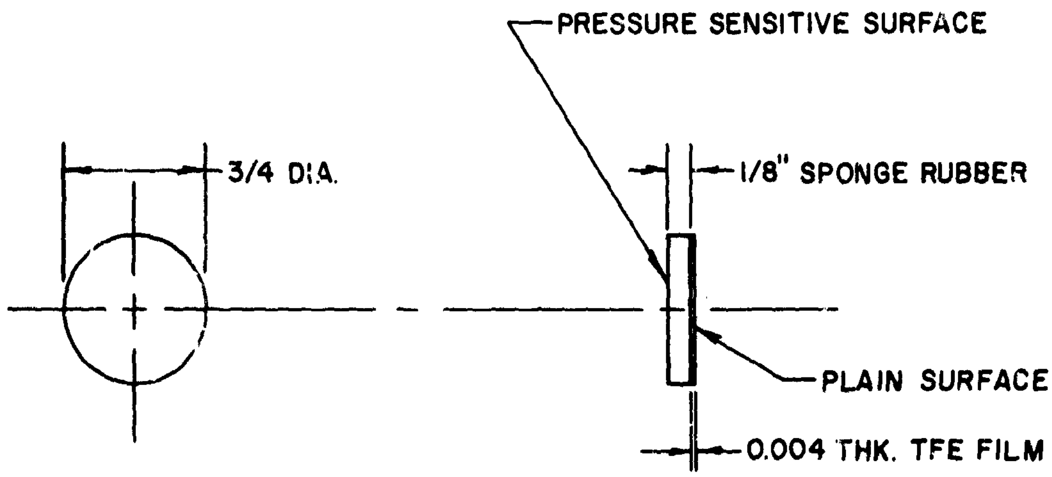


Figure 30.   Washer-Sealing

SECTION IV

CONCLUSIONS AND RECOMMENDATIONS

Based on these data, we conclude that the smoke-screening technique, as originally conceived, is both feasible and effective:

1. Ejection tests indicate the present units can be dispersed from the SUU-13/A system.

2. Large-scale field tests demonstrated that a white and highly-obscuring smoke screen can be produced to persist 10 minutes in a 0-2 mph wind.

3. The candidate agents are noncorrosive, nonirritating, and most probably nontoxic.

4. Various storage conditions have no adverse effects on the proposed agents.

5. Drop tests showed the units resist severe impact, such as might be imparted by dispersal from low-altitude, high-speed aircraft.

6. The cloud, pour, and fire points of the proposed agents are all below -40°F.

7. Replacement of the Bellofram diaphragm by three weighted tubes will insure proper orientation in water.

8. Alterations in fabrication of the smoke generator should prevent occasional rupturing of units during dissemination.

We also feel that our progress warrants further work, including:

1. Complete characterization of candidate agents 90223-7 and 90223-9.

2. Incorporation of three tubes, with weighted intakes, into the present disseminator to improve its floating position in water.

3. Construction of these modified units and fabrication of their parts by improved techniques.

4. Larger-scale static field tests to evaluate more fully the smoke screens, their obscuring power, screen length and height, and other parameters under various environmental conditions.

5. Submission of prototype units, filled with smoke agents, to the U. S. Air Force for evaluation by launching from low-altitude, high-speed aircraft.

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APPENDIX I

DETAILED PROCEDURE FOR SMOKE TUNNEL TEST

1. CALIBRATION

a. Clean dispensers and install clean or new nozzles.
b. Charge dispensers with 75 ml of n-hexane.
c. Disseminate n-hexane under 50 psig of nitrogen pressure and record discharge time. Nozzle flow rates should not deviate more than ± 1.5% from the average flow rate based on 8 samples.

2. DISPENSER PREPARATION

a. Flush dispensers thoroughly with nitrogen and cover nozzles with rubber caps.
b. Remove the top toggle valve under a nitrogen atmosphere.
c. Charge the dispenser with 75 ml of the candidate agent.
d. Replace the toggle valve and store the dispenser in an upright position until test.

3. SMOKE TUNNEL PROCEDURE

a. Clean plastic Plexiglas windows and the exhaust pipe.
b. Install and secure dispenser; pressurize with 75 psig of nitrogen.
c. Turn on the compressors and blowers. Allow the system to equilibrate.
d. Turn on all electrical equipment. Adjust the recording instrument to obtain a suitable baseline.
e. Calibrate instrumentation.
f. Actuate the unit for the desired run time by opening the toggle valve.
g. After the tunnel is clear of smoke, actuate the unit repeatedly until the feed material is exhausted.

4. CLEAN-UP PROCEDURE -- TUNNEL

a. Remove the bottom of the smoke tunnel and separate the components of the exhaust line.
b. Scrape any sludge into a chemical waste container and dispose.
c. Wash surfaces of tunnel bottom and interior of the exhaust pipes with n-hexane.
d. Reassemble.

5. CLEAN-UP PROCEDURE -- FEED UNITS

a. In an outdoors area, vent the chamber through both toggle valves.
b. Close both valves and carefully remove the nozzle; occasionally rinse the nozzle in n-hexane or No. 9 oil while doing this.
c. Remove the top toggle valve and rinse the brass cartridge well with n-hexane.

d. Disassemble the nozzle; brush off all solids adhering to components and then wash in dilute hydrochloric acid.
e. Rinse nozzle components with acetone, followed by n-hexane. Store until ready for use.
f. Rinse the brass chamber and the toggle valves with acetone, followed by n-hexane flush.
g. Reassemble the dispenser. Flush with air, followed by 5-7 minutes of nitrogen flush.
h. Close all valves and put a rubber cup over the end of the nozzle.

APPENDIX II

SMOKE NUMBER CALCULATIONS

As previously given:

$$VSN_A = \frac{(10)\ (A_A)}{A_{FM}} \tag{1}$$

where:

VSN_A = Volumetric smoke number of agent

10 = Arbitrarily assigned volumetric smoke number of Agent FM

A_A = Area under time-percent absorption curve with agent

A_{FM} = Area under time-percent absorption curve with FM

Previous work had shown that:

$$VSN_{90622\text{-}T} = \frac{(10)\ (A_{90622\text{-}T})}{[illegible]} = 15.2$$

or:

$$\frac{15.2}{A_{90622\text{-}T}} = \frac{10}{A_{FM}} \tag{2}$$

Using equation (2) and substituting equation (1):

$$VSN_A = \frac{(15.2)\ (A_A)}{A_{90622\text{-}T}} \tag{3}$$

Thus, equation (3) was used in volumetric smoke number calculations.

An analogous procedure was used to develop an equation for mass smoke number (MSN):

$$MSN_A = \frac{10\ (A_A)}{A_{FM}} \cdot \frac{\rho_{FM}}{\rho_A} \tag{4}$$

$$MSN_{90622\text{-}T} = \frac{10(A_{90622\text{-}T})\ \rho_{FM}}{A_{FM}\ \rho_{90622\text{-}T}}$$

By experiment:

$$\frac{(31.1)\ (\rho_{90622\text{-}T})}{A_{90622\text{-}T}} = \frac{(10)\ (\rho_{FM})}{A_{FM}}$$

Substituting into equation (4):

$$MSN_A = \frac{31.1\ (A_A)}{A_{90622\text{-}T}} \cdot \frac{\rho_{90622\text{-}T}}{\rho_A} \qquad (6)$$

Equation (6) was used in MSN calculations.

Relative Smoke Densities of 90223-4 by Area Measurements

Run 1

Measurement No.	Curve 1	2	3	4	5	6	7	8	9
1	24.8	24.6	25.3	22.1	24.5	23.0	26.2	15.6	3.9
2	24.8	24.6	25.0	22.4	24.2	22.9	26.0	15.3	3.8
Avg.	24.8	24.6	25.15	22.25	24.35	22.95	26.1	15.45	3.85

Total area 189.5 cm^2

Run 2

Measurement No.	Curve 1	2	3	4	5	6	7	8	9	10	11	12
1	19.1	17.8	16.7	16.7	16.8	15.2	16.3	16.4	18.3	29.4	15.0	3.1
2	18.9	17.7	16.9	16.4	17.0	15.3	16.1	16.6	18.1	29.4	15.0	3.2
Avg.	19.0	17.75	16.8	16.55	16.9	15.25	16.2	16.5	18.2	29.4	15.0	3.15

Total area 200.7 cm^2

Relative Smoke Densities of 90622-T by Area Measurements

Run 1

Measurement No.	Curve 1	2	3	4	5	6	7	8	9	10	11
1	11.9	15.9	13.8	15.6	15.3	14.6	17.0	17.3	27.1	12.1	6.2
2	12.0	15.7	13.6	15.5	15.3	14.6	17.0	17.3	27.0	12.0	5.9
Avg.	11.95	15.8	13.7	15.55	15.3	14.6	17.0	17.3	27.05	12.05	6.05

Total area 166.35 cm^2

Relative Smoke Densitites of 90622-T by Area Measurements (cont'd)

Run 2

Measurement No.	Curve 1	2	3	4	5	6	7	8	9
1	40.0	22.4	21.2	21.2	21.4	18.5	8.9	5.7	1.5
2	39.2	22.5	21.1	21.3	21.4	18.6	9.2	5.6	1.5
Avg.	39.6	22.45	21.15	21.2	21.4	18.55	9.05	5.65	1.5

Total area 160.55 cm^2

Run 3

Measurement No.	Curve 1	2	3	4	5	6	7	8
1	33.4	19.7	21.1	21.2	22.4	16.1	16.1	10.0
2	33.4	19.6	21.1	21.2	22.4	16.0	16.0	9.9
Avg.	33.4	19.65	21.1	21.2	22.4	16.05	16.05	9.95

Total area 159.8 cm^2

Run 4

Measurement No.	Curve 1	2	3	4	5	6	7	8	9	10	11	12
1	17.4	17.0	15.7	16.4	15.4	16.3	11.0	16.0	19.6	24.1	13.3	8.7
2	17.2	16.9	15.6	16.3	15.5	16.1	11.2	15.9	19.8	24.3	13.0	8.9
Avg.	17.3	16.95	15.65	16.35	15.45	16.2	11.1	15.95	19.7	24.2	13.15	8.8

Total area 190.8 cm^2

Average of Run 1 and Run 2 - 163.45 cm^2
Average of Run 3 and 4 - 175.3 cm^2

Volumetric Smoke Number

Using equation (3),

$$VSN(90223\text{-}4) = \frac{(15.2)\ (A_{90223\text{-}4})}{A_{90622\text{-}T}}$$

Run 1

$$A_{90223\text{-}4} = 189.5 \text{ cm}^2$$

$$A_{90622\text{-}T} = 163.45 \text{ cm}^2$$

$$VSN(90223\text{-}4) = \frac{(15.2)\ (189.5)}{163.45} = 17.6$$

Run 2

$$A_{90223\text{-}4} = 200.7 \text{ cm}^2$$

$$A_{90622\text{-}T} = 175.3 \text{ cm}^2$$

$$VSN(90223\text{-}4) = \frac{(15.2)\ (200.7)}{175.3} = 17.4$$

Mean VSN = 17.5 for 90223-4

Mass Smoke Number

Using equation (6),

$$MSN(90223\text{-}4) = \frac{(31.1)\ (A_{90223\text{-}4})}{A_{90622\text{-}T}} \cdot \frac{\rho_{90622\text{-}T}}{\rho_{906223\text{-}4}}$$

Run 1

$$A_{90223\text{-}4} = 189.5 \text{ cm}^2$$

$$A_{90622\text{-}T} = 163.45 \text{ cm}^2$$

$$\rho_{90622\text{-}T} = 0.850$$

$$\rho_{90223\text{-}4} = 0.898$$

$$MSN = \frac{(13.1)\ (189.5)\ (0.850)}{(163.45)\ (0.848)} = 34.1$$

Run 2

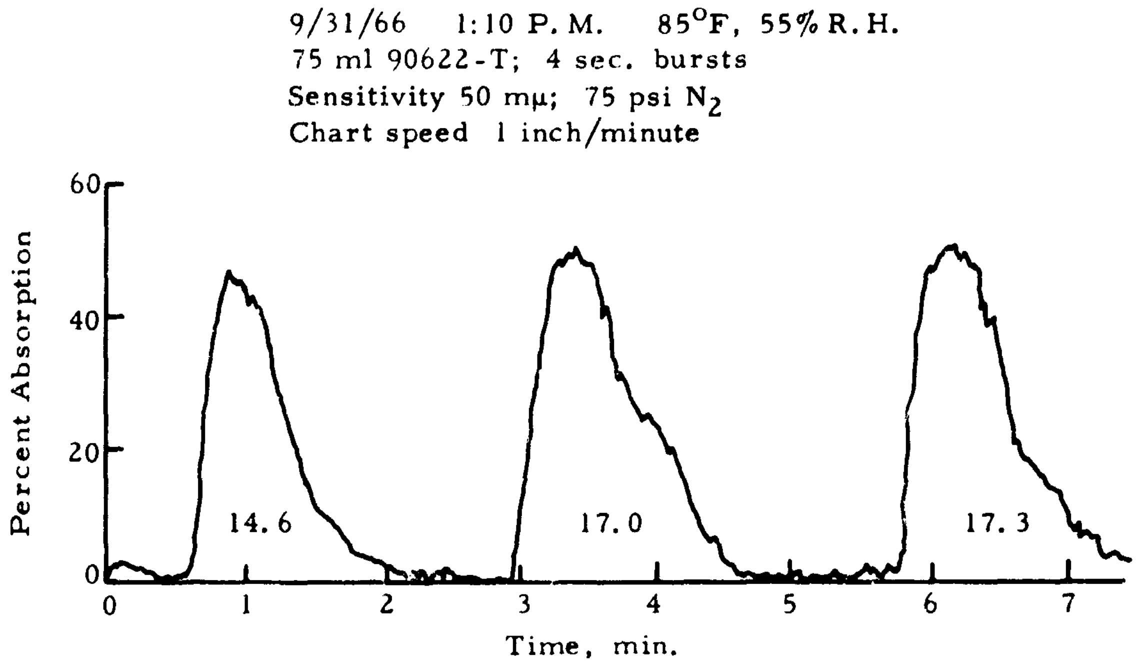
$$A_{90223\text{-}4} = 200.7 \text{ cm}^2$$

$$A_{90622\text{-}T} = 175.3 \text{ cm}^2$$

$$MSN = \frac{(31.1)\ (200.7)\ (0.850)}{(175.3)\ (0.898)} = 33.9$$

Mean MSN = 34.0 for 90223-4

Typical curves for 90223-4 and 90622-T are shown in Figure II-1



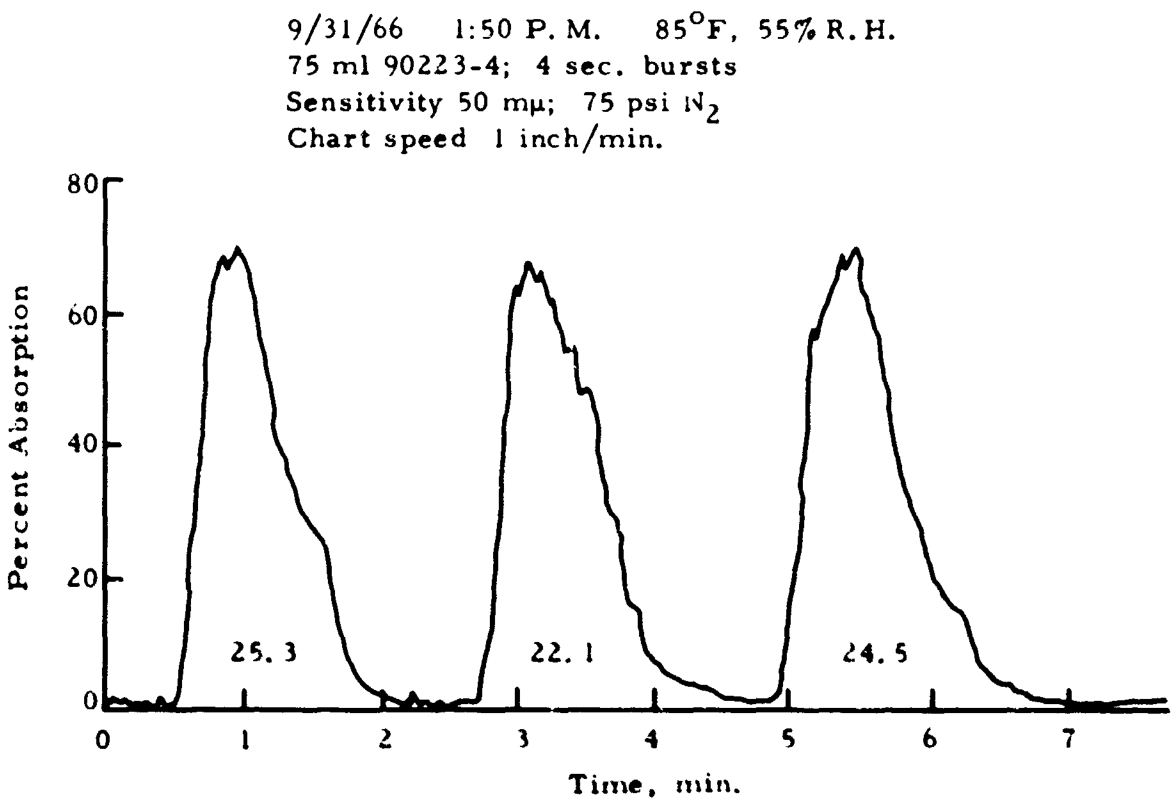


Figure II-1. Typical Time-Transmission Curves

APPENDIX III

DETAILED PROCEDURE FOR TOTAL OBSCURING POWER (TOP) MEASUREMENTS

1. AERIAL DISSEMINATION

a. Dispenser Preparation

(1) Flush dispenser thoroughly with nitrogen and cover nozzles with rubber caps.
(2) Remove the top toggle valve while under an inert nitrogen atmosphere.
(3) Charge the dispenser with 100 ml of the candidate agent.
(4) Replace the top toggle valve and store the dispenser in an upright position until test.

b. TOP Procedure

(1) Clean plastic Plexiglas observation windows and light source.
(2) Install and secure dispenser in a vertical position with nozzle pointing down; pressurize with 100 psig of nitrogen.
(3) Turn on fans and light source. Allow the system to equilibrate.
(4) Shut off all viewing lights.
(5) Actuate the unit and simultaneously start a stopwatch.
(6) At intervals of one minute, record the distance at which the light source is barely visible.

c. Clean-Up Procedure

(1) TOP Apparatus - Actuate large blower and open doors to permit escape of smoke.

(2) Feed Units - Same as in Appendix I.

2. UNDERWATER DISSEMINATION

The procedure is exactly the same as for aerial dissemination except for two modifications:

a. Charge units with 800 ml of the candidate agent.
b. Place the nozzle under the surface of water contained in a five-gallon can.

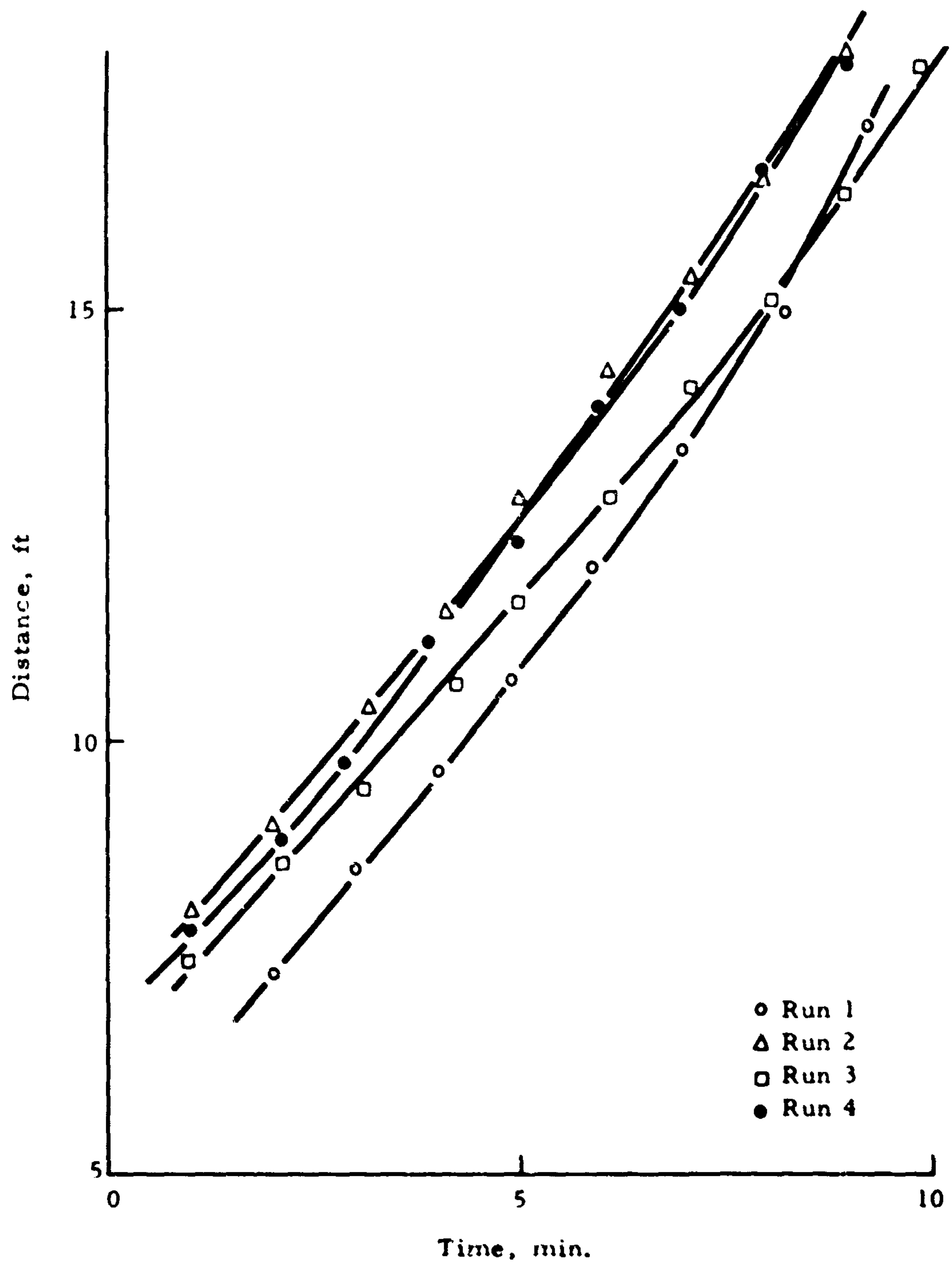


Figure III-1. TOP Measurements of 90223-8

APPENDIX IV

EXAMPLE OF TOP CALCULATION

$$TOP = \frac{\left(\frac{1}{D}\right) V}{W}$$

D = distance to light source, ft
V = volume of test chamber, cu ft
W = weight of candidate agent, lb

1. Calculation of D for 90223-8

Run 1			Run 2			Run 3			Run 4		
Min	Sec	D,ft	Min	Sec	D,ft	Min	Sec	D,ft	Min	Sec	D,ft
1	-	-	1	0	8.05	1	0	7.45	1	0	7.80
2	0	7.30	2	0	9.05	2	5	8.55	2	5	8.85
3	0	8.50	3	10	10.45	3	5	9.45	2	55	9.75
4	0	9.65	4	5	11.50	4	10	10.65	3	55	11.20
4	55	10.70	5	0	12.85	5	0	11.60	5	0	12.30
5	55	12.00	6	5	14.30	6	5	12.80	6	0	13.90
7	0	13.35	7	5	15.25	7	5	14.10	7	0	15.00
8	15	14.95	8	0	16.50	8	5	15.10	8	0	16.55
9	25	17.10	9	0	17.95	9	0	16.35	9	0	17.85
						9	55	17.80			

Graphically, the mean D = 11.65 feet (see Figure 32)

2. Volume of Test Chamber

$$V = 8 \times 8 \times 20 = 1280 \text{ cubic feet}$$

3. Weight (W) of Agent 90223-8

$$W = 100 \text{ ml} \times \frac{0.912 \text{ g}}{\text{ml}} \times \frac{1 \text{ lb}}{453.6 \text{ g}} = 0.201 \text{ lb}$$

4. TOP

Substituting,

$$TOP = \frac{\left(\frac{1}{11.65 \text{ ft}}\right)\left(1280 \text{ ft}^3\right)}{0.201 \text{ lb}} = 547 \text{ ft}^2/\text{lb}$$

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(3) Aluminum Alkyls and Other Metal Alkyls, Ethyl Corporation, New York.

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Air Force Systems Command
Eglin Air Force Base, Florida 32542

13 ABSTRACT The objective is to develop nontoxic, noncorrosive, and nonirritating aluminum alkyl-based smokes and a delivery system adaptable to the SUU-13/A system for low-altitude, high-speed aircraft. Quantitative evaluation of their smoke densities proved them to be comparable to, or superior than, Agent FM (titanium tetrachloride). All agents have low pour points (< -50°C), low cloud points (< -70°C), and low fire and flash points (-40 to -60°C). Two agents were subjected to storage surveillance tests at -40°F, ambient temperature and +160°F for a period of three months and showed excellent storage stability. The smoke from these two agents has no deleterious effect on seven metals and eight polymers. Agents are stable for several hours at 212°F. The prototype disseminator is a cylindrical aluminum container 4-5/8 inches in diameter and about 9-3/4 inches long. It contains three fuel oil spray nozzles. The disseminator generates a dense white smoke for 6-8 minutes. The units have been fired successfully from SUU-13/A ejector tubes and functioned normally. They also performed satisfactorily after 40-foot drop tests on steel. Two large-scale field tests with these units and our agents demonstrated the feasibility and effectiveness of this smoke dissemination technique. The disseminators are adaptable to the SUU-13/A system.

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14 KEY WORDS	LINK A ROLE	LINK A WT	LINK B ROLE	LINK B WT	LINK C ROLE	LINK C WT
Smoke						
Aluminu. alkyl						
Triethylaluminum						
Dissemination						
SUU-13/A system						
Obscuring power						

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