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RESEARCH MEMORANDUM

THE APPEARANCE OF A BORIC OXIDE EXHAUST CLOUD FROM A TURBOJET ENGINE OPERATING ON TRIMETHYLBORATE FUEL

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

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THE APPEARANCE OF A BORIC OXIDE EXHAUST CLOUD FROM A TURBOJET ENGINE OPERATING ON TRIMETHYLBORATE FUEL*

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SUMMARY

An investigation was conducted on the size and density of the boric oxide exhaust cloud from a J47-25 turbojet engine operating on trimethylborate fuel at sea-level static conditions. Movies and still photographs were taken from the ground and from a helicopter. Objects could not be perceived through the main body of the cloud at distances up to 800 feet from the engine.

Data are included on the amount of fallout from the cloud and the concentration of boric oxide in the cloud.

A radiation detection device was set up to determine whether the glowing oxide particles would be more susceptible than hydrocarbon exhaust gases to this type of tracking device. The device showed an increase in radiation by a factor of 3 for trimethylborate over that for JP-4.

INTRODUCTION

For the past several years the NACA Lewis laboratory, in cooperation with the Bureau of Aeronautics, Department of the Navy, as part of Project Zip, has investigated the use of liquid boron compounds as fuels for jet aircraft engines. Since compounds of this type produce solid boric oxide as an exhaust product, it has been recognized from the start that unique operational problems will be encountered in actual service. For example, boric oxide in sufficient dosages is toxic to both plant and animal life; therefore, serious hazards will exist if the oxide is dispersed indiscriminately over inhabited areas on and around airfields. Furthermore, the problem may be more serious with carrier-based aircraft unless proper protection is provided for personnel aboard carriers.

From a military viewpoint, another problem of importance is the visibility of the boric oxide exhaust trail to the naked eye and to tracking devices. Also, a boric oxide cloud might be expected to hamper general visibility around airports, or at sea, to a greater or less degree.

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* Title, Unclassified [redacted]

Since no tests had been conducted in which the boric oxide was exhausted to the atmosphere without a water scrubbing treatment, the NACA Lewis laboratory operated an engine on trimethylborate - methyl alcohol azeotrope to demonstrate the magnitude of the exhaust problem. This test was made at sea-level conditions, and the exhaust was permitted to disperse freely into the atmosphere. In order to avoid hazard to the surrounding area, the test was limited to about 4 minutes duration. The primary objective of the test was to show the extent of spread of the exhaust trail and the density of the trail resulting from boric oxide. For this reason most of the observations were photographic; however, efforts were made to collect samples of solid oxide from the exhaust stream. 4201

It is expected that the difference in emissivity between the trimethylborate exhaust products and the gases from the hydrocarbon fueled engines could affect the usefulness of radiation tracking devices. A radiation measuring instrument was set up to compare this difference.

A motion picture of this test has been prepared and is available on loan from the National Advisory Committee for Aeronautics, 1512 H Street N.W., Washington 25, D. C.

FUEL

Trimethylborate - methyl alcohol azeotrope was used as the fuel for this investigation. The physical properties are given in table I. Inasmuch as this fuel had been in storage for a considerable period of time, a check was made for suspended material and hydrolysis immediately prior to the test. The fuel was found to be satisfactory.

ENGINE INSTALLATION

The J47-25 turbojet engine used for this investigation was mounted in a test stand at the edge of the NACA hangar apron at Cleveland Hopkins Airport. The installation is shown in figure 1. A mat woven of steel cables was suspended over the engine to provide protection for observers and operating personnel in the event of an engine failure.

Standard combustors were used. The standard fuel injectors were modified to accommodate the high flow rates of trimethylborate.

TEST CONDITIONS

The engine was operated at the following conditions:

Ambient pressure, lb/sq in. abs	14.5
Ambient temperature, °F	72
Humidity, percent	57
Wind direction	from SSW
Wind velocity, knots	16
Engine exhaust direction	SE by E
Engine speed, percent of rated	94
Air flow, lb/sec	97.8
Fuel flow, lb/hr	14,400
Tailpipe temperature, °F	1310

PROCEDURE

The engine was started and warmed up on JP-4 fuel. Without interruption of operation, JP-4 flow was decreased and trimethylborate fuel was throttled in. Operation on trimethylborate was continued for about 4 minutes after which operation on JP-4 was resumed.

The engine exhaust stream was emitted in an easterly direction. The wind was from the south-southwest at the time of the test. On the basis of the expected path the wind-borne exhaust cloud would follow, beakers partly filled with water were located on the ground as shown in figure 2 in an effort to determine the fallout concentration. In addition, vertical sampling of the exhaust cloud was attempted by suspending evacuated bottles at various levels from cords supported by weather ballons.

During operation on trimethylborate fuel, movies and still photographs were taken from the ground and from a helicopter.

Radiation measurements were made with a Brown low-temperature radiation pickup. This is a laboratory instrument intended mainly for short-distance measurements. Its normal range is 125° to 700° F for bodies having emissivities approaching 1. The wave-length sensitivity of the instrument is 0.3 to 10 microns. It was located 14 feet from and at right angles to the engine centerline at a point 2 feet behind the exhaust nozzle.

DISCUSSION OF RESULTS

At the operating conditions of the test, 3310 pounds per hour of boric oxide were being formed in the engine combustors. The total boric oxide exhausted to the atmosphere during the 4-minute test was approximately 220 pounds. This quantity of oxide would be about 1/3 that to be expected with fuels such as ethyldecaborane or pentaborane at sea-level operation on an equal heat input basis. Heating values and B_2O_3 yields of several boron fuels are shown in the following table:

Fuel	Heat of combustion, Btu/lb	B_2O_3, lb/lb of fuel	B_2O_3, lb/100,000 Btu
$(CH_3O)_3B\text{-}CH_3OH$[a]	8,052	0.23	2.9
B_5H_9	29,130	2.76	9.5
$B_{10}H_{13}C_2H_5$	26,400	2.32	8.8
$B_5H_8C_3H_7$	24,800	1.65	6.6

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[a]70-30 weight percent (approx.) mixture of trimethylborate-methyl alcohol.

The oxide produced during this sea-level static test with trimethylborate was about 1.4 times as great as that produced by pentaborane at 50,000 feet and Mach 0.8 (ref. 1); however, the amount of oxide produced at altitude would be spread out over a considerable distance at that speed.

Visual Observation

Boric oxide in the exhaust gases was visible as soon as trimethylborate entered the engine. The density of the exhaust cloud increased proportionately with the increasing trimethylborate - JP-4 ratio. After 4 minutes of operation on trimethylborate, the boric oxide cloud had risen to a height of about 2000 feet. Figure 3(a) is a photograph of the cloud taken from the helicopter. The angle of this photograph is such that the cloud appears denser than it would in a right-angle view. The centerline of the cloud rose as it was blown away from the engine; however, dispersion of the cloud kept the lower edge near the ground. At distances up to 800 feet downwind of the engine, objects could not be seen through the cloud when it was forced to the ground. At 1000 feet and beyond, objects could be perceived through the cloud. The cloud moved off with the wind and spread slowly after shutdown. It was still visible about 10 minutes later.

Figure 3(b) shows the cloud from an angle looking toward the exhaust of the engine. The cloud has been caught by the wind and is being deflected to the right.

Oxide Fallout and Concentration

The results of the analysis of the boric acid in the sampling beakers and the concentration of boric oxide in the evacuated bottles is indicated in figure 2. The concentration of boric oxide in the beakers appears to be a maximum near the center of the layout, which indicates good coverage of the exhaust gases. Although the cloud itself was dense, there was no evidence of its path on the ground after the test.

Radiation from Glowing Oxide Particles

The radiation measurements of the exhaust from JP-4 and from trimethylborate fuel are given in table II. The pickup output increased by a factor of 3 as the fuel was changed from JP-4 to trimethylborate.

SUMMARY OF RESULTS

The results of the sea-level test on the size and density of the boric oxide exhaust cloud from a J47-25 turbojet engine operating for 4 minutes on trimethylborate fuel were as follows:

1. The boric oxide in the exhaust (about 1/3 that of ethyldecaborane fuel) formed a strongly visible cloud, which rose to a height of about 2000 feet. Objects viewed normal to the cloud were obscured at distances up to 800 feet from the engine.

2. The ground under the exhaust plume was free of any visible trace of boric oxide. The maximum concentration measured 460 feet from the engine was 0.0224 milligram per square centimeter.

3. The susceptibility of the boric oxide exhaust to radiation detection was 3 times that of JP-4 exhaust.

Lewis Flight Propulsion Laboratory
National Advisory Committee for Aeronautics
Cleveland, Ohio, July 30, 1956

REFERENCE

1. Useller, James W., and Jones, William L.: Extended Operation of Turbojet Engine with Pentaborane. NACA RM E55L29, 1956.

TABLE I. - PHYSICAL PROPERTIES OF TRIMETHYLBORATE -

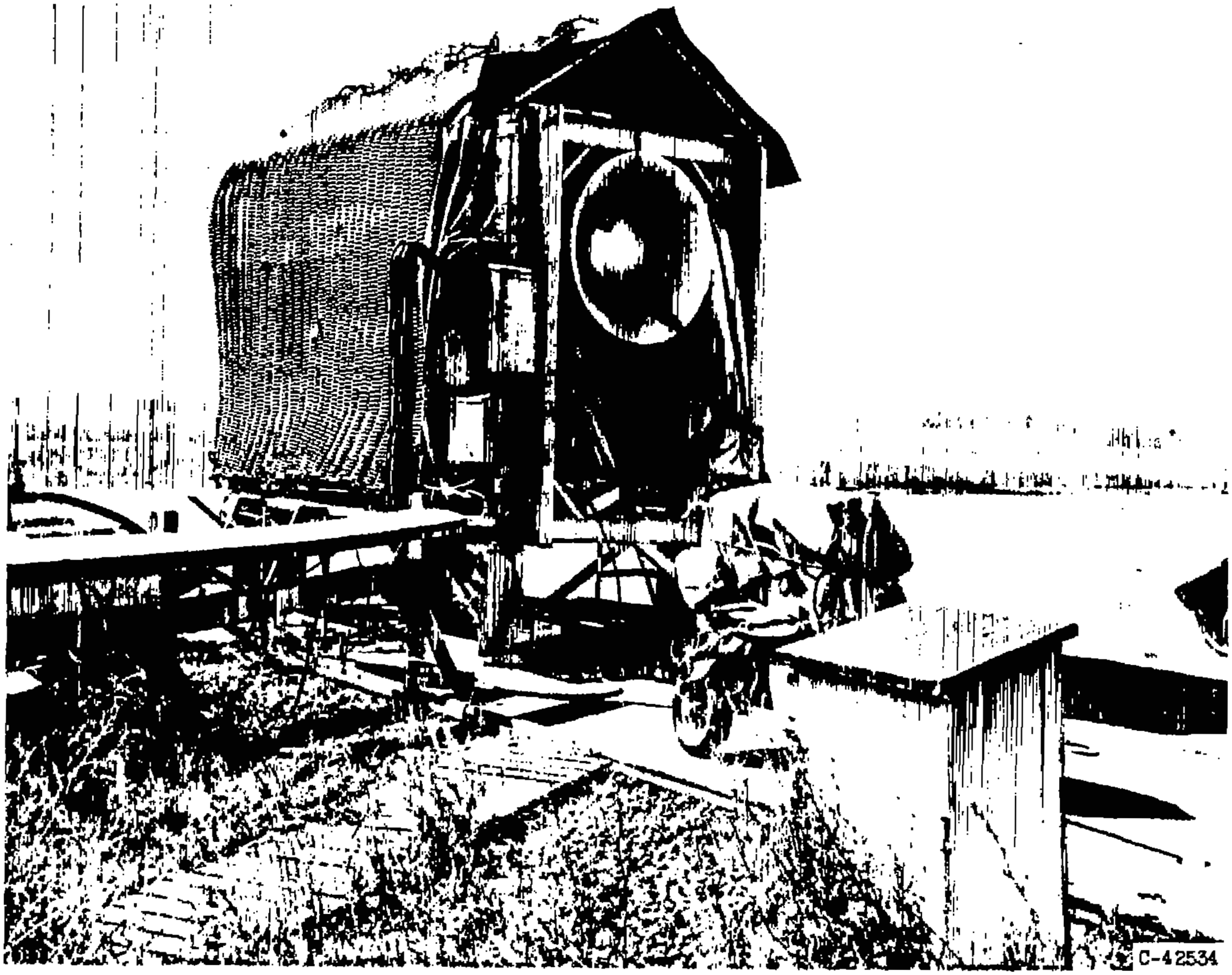
METHYL ALCOHOL AZEOTROPE

Formula	$(CH_3O)_3B\text{-}CH_3OH$
Molecular weight	136
Heating value, Btu/lb	8052
Pounds of boric oxide formed per pound of fuel	0.23
Pounds of boric oxide formed per million Btu	32
Specific gravity at 60° F	0.884

TABLE II. - RADIATION PICKUP MEASUREMENTS

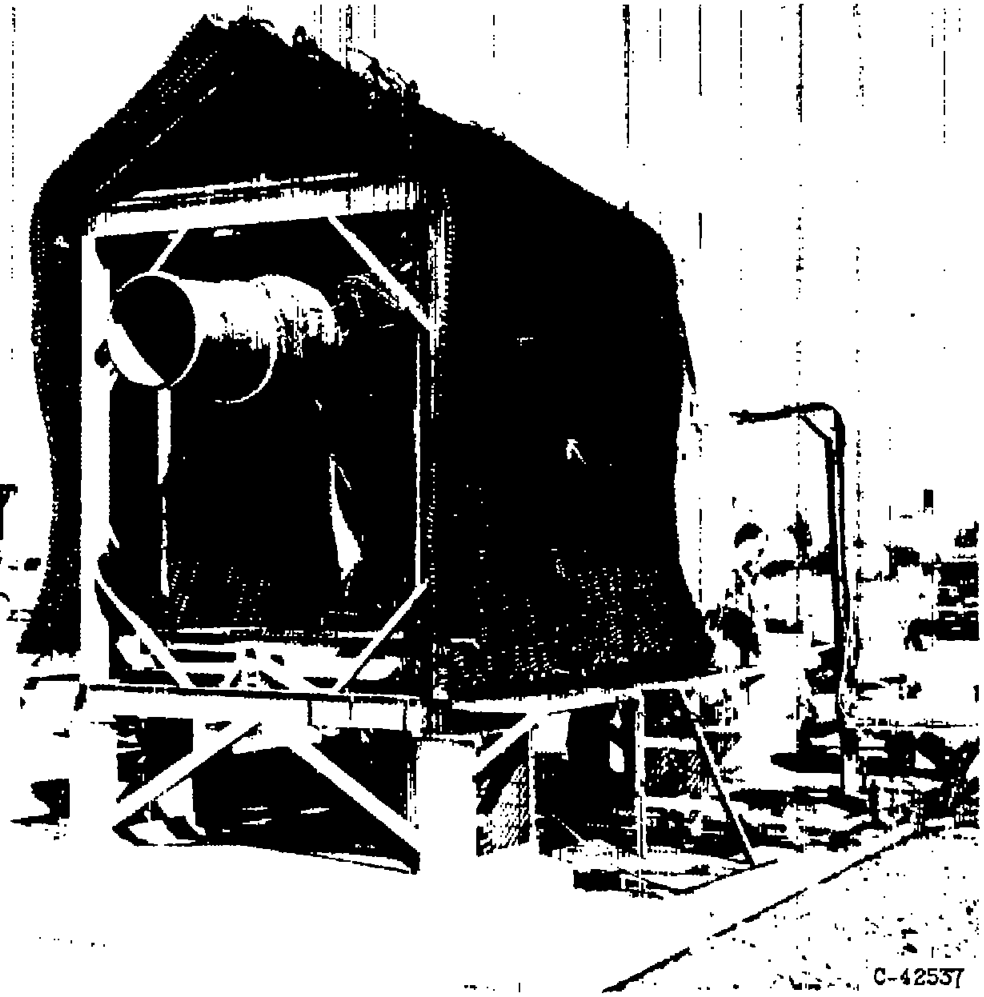
Time	Millivolts	
9:05	0.35	JP-4 fuel flow being increased to about 85 percent of rated speed
07	.30	
08	.29	
11	.50	
9:12	0.62	Gradual change from 100 percent JP-4 to 100 percent trimethylborate
13	.69	
9:14	1.20	Increase to 95 percent rated speed with trimethylborate
15	1.47	
9:16	1.16	Change from trimethylborate to JP-4
19	.78	
21	.73	
9:23	0.48	Shutdown
24	.05	
30	.03	

[redacted]



(a) Engine inlet.

Figure 1. - Installation of J47-25 turbojet engine for smoke tests.



(b) Engine exhaust.

Figure 1. - Concluded. Installation of J47-25 turbojet engine for smoke tests.

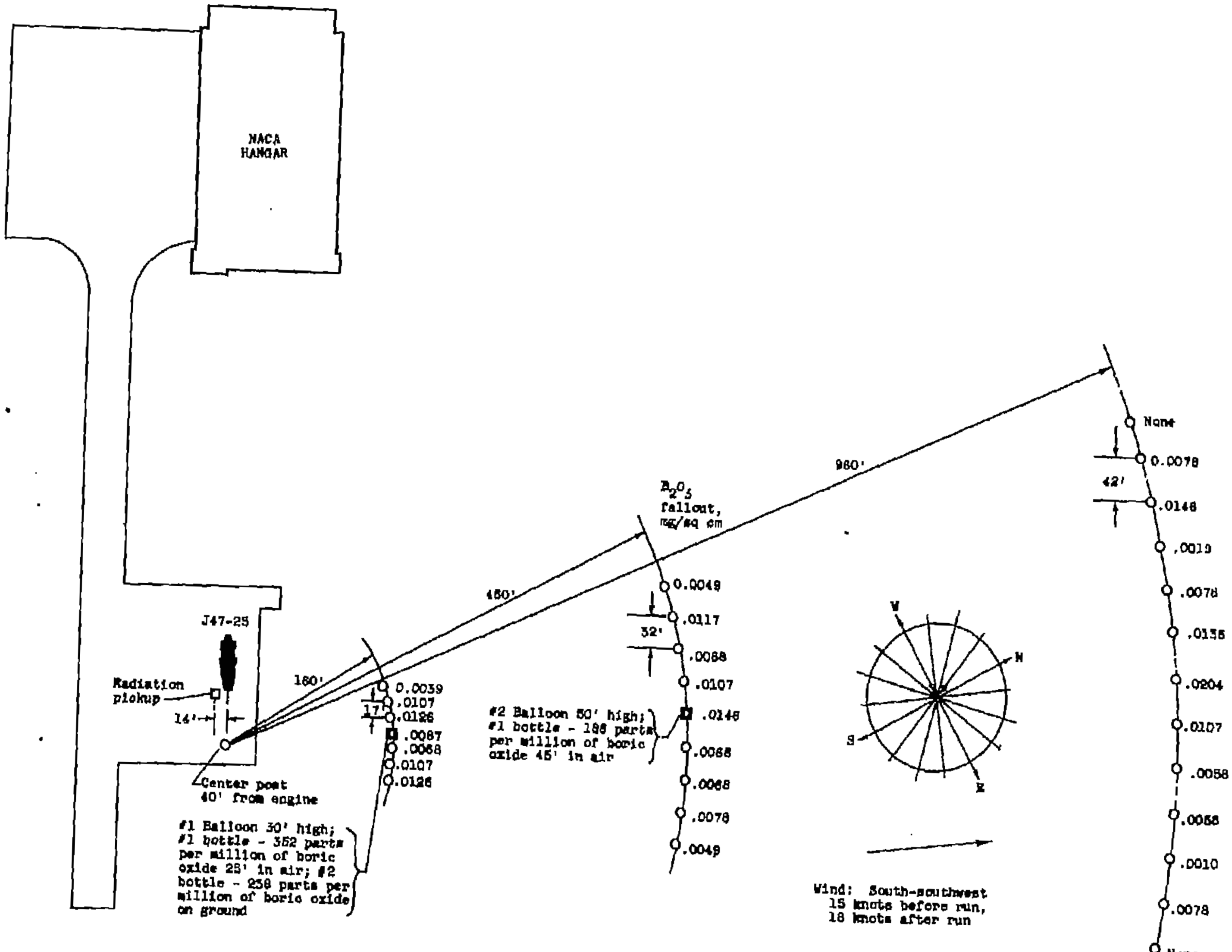
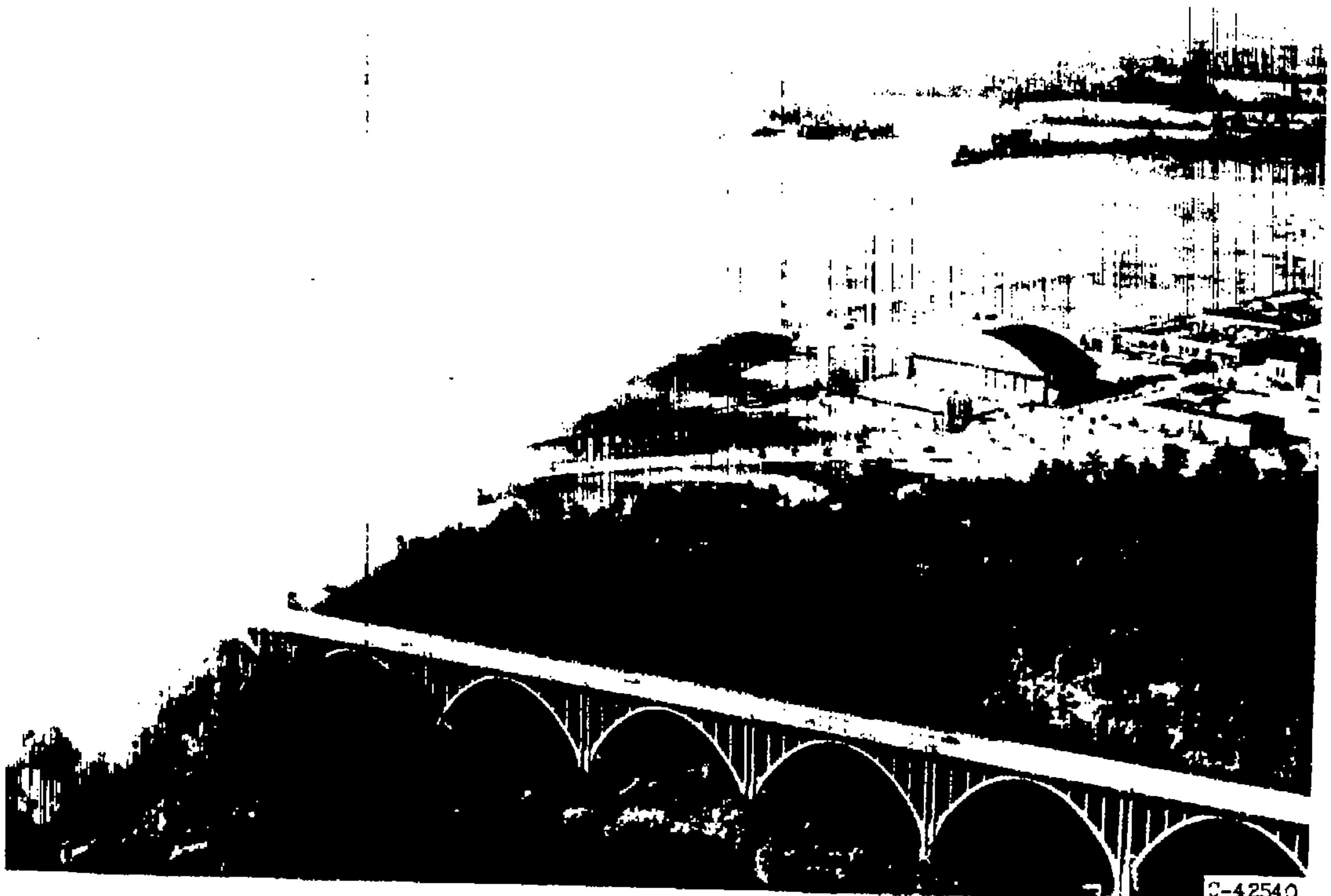
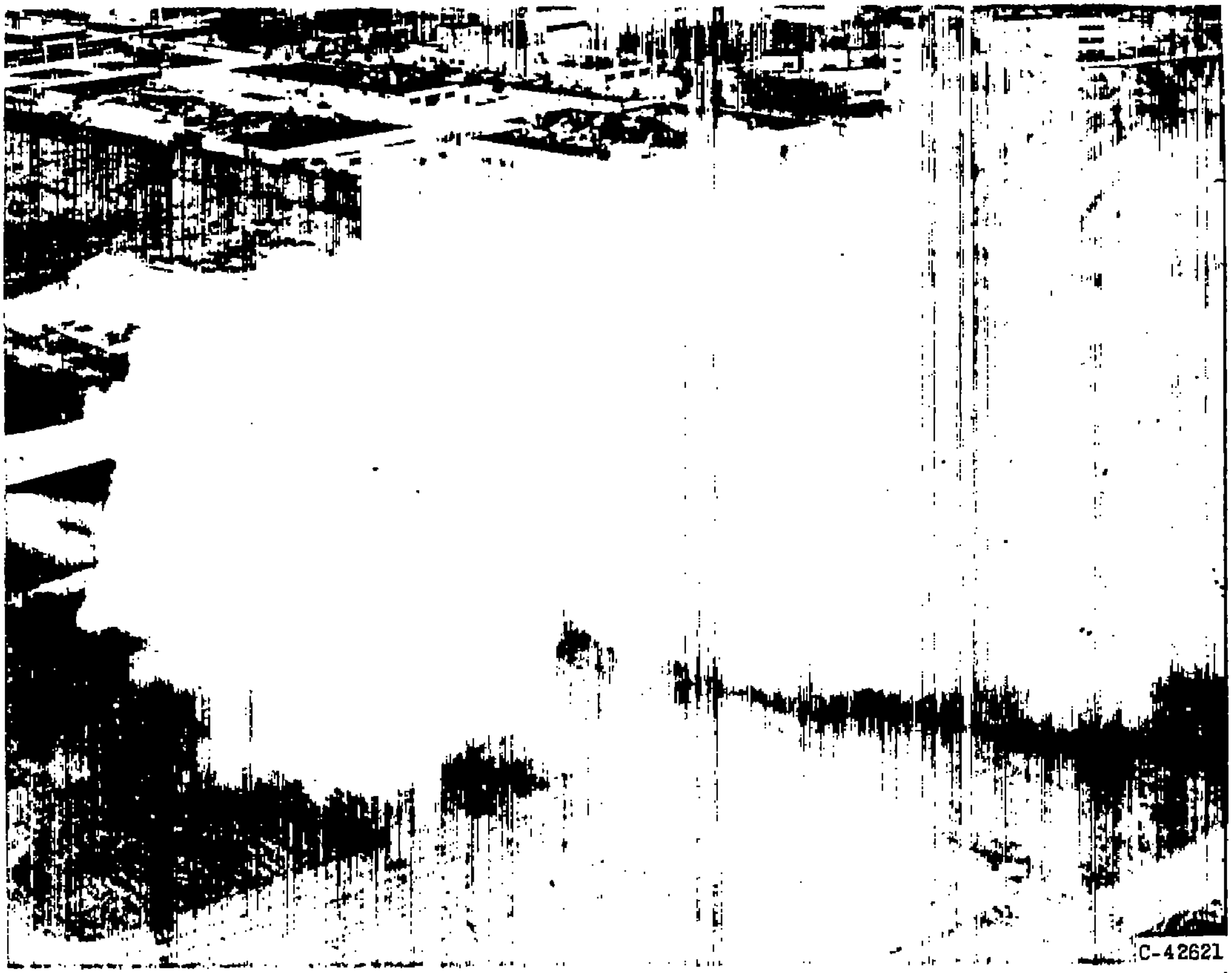


Figure 2. - Arrangement of fallout and air-borne dust sampling devices and the concentrations collected.



(a) View from helicopter 2500 yards downwind of engine.

Figure 3. - Boric oxide smoke cloud from exhaust of turbojet engine burning trimethyl-borate fuel.



(b) View from helicopter opposite engine exhaust nozzle.

Figure 3. - Concluded. Boric oxide smoke cloud from exhaust of turbojet engine burning trimethyl-borate fuel.

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