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Comparative Nozzle Study for Applying Aqueous Film Forming Foam on Large-Scale Fires

LEVEL II

DEPARTMENT OF THE NAVY
NAVAL RESEARCH LABORATORY
WASHINGTON, D.C. 20375

APRIL 1978

FINAL REPORT FOR PERIOD NOVEMBER 1976-SEPTEMBER 1977

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CIVIL AND ENVIRONMENTAL ENGINEERING DEVELOPMENT OFFICE
(AIR FORCE SYSTEMS COMMAND)
TYNDALL AIR FORCE BASE
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A large-scale fire test program was conducted to evaluate the relative fire-fighting effectiveness of applying aqueous film forming foams (AFFF) through commercially available air-aspirating and non air-aspirating nozzles. The Navy MB-1 and P-4A and Air Force P-4 aircraft fire-rescue vehicles were used as nozzle test-beds. Nozzles with rated capacities of 250 gpm and 750 to 800 gpm were tested and evaluated on 4 square feet and 8000 square feet JP-4 fuel fires, respectively. Eight of the 16 fires conducted contained an aircraft mock-up.

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The lower expansion, more fluid, longer reach aqueous film forming foams generated with the non air-aspirating type nozzles were found to provide superior fire extinguishing effectiveness compared to the air-aspirating type nozzles. Air-aspirated foams required approximately 50 percent longer to achieve 90 percent fire control than the non air-aspirated foams. No discernible difference in burnback resistance was found for either type of foam.

PREFACE

This report was prepared by the Fire Suppression Section, Combustion and Fuels Branch, Chemistry Division, Naval Research Laboratory under AFCEC project order 77-018, Job Order Number 414N4001, for Detachment 1 (CEEDO) ADTC, Tyndall AFB FL.

This report summarizes work done between November 1976 and September 1977. Capt. Lawrence W. Redman was the Project Officer.

This report has been reviewed by the Information Office (OI) and is releasable to the National Technical Information Service (NTIS). At NTIS it will be available to the general public, including foreign nations.

Appreciation is expressed to Mr. Henry B. Peterson, Naval Research Laboratory, and Mr. Robert L. Darwin, Naval Material Command, for their assistance and overall technical support. The excellent cooperation and assistance provided by the members of the Fire Department of the Naval Weapons Center under Fire Chief W. R. Knight and Assistant Chief W. A. Pahl is gratefully acknowledged.

This technical report has been reviewed and is approved for publication.

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SECTION I

INTRODUCTION

BACKGROUND STUDIES AND TEST PROGRAMS

In mid 1960 the Naval Research Laboratory conducted studies (References 1 and 2) which proved the fire extinguishing superiority of aqueous film forming foam (AFFF) over protein foam on large-scale fires when utilized in crash rescue and fire fighting vehicles. The air-aspirating nozzles and foam pumps used as foam-generating equipment were originally designed for protein foam concentrate. Ultimately the Navy and Air Force converted these vehicles to AFFF use without any changes to the foam-generating equipment. One of the recommendations of these studies was to seek the optimum foam makers for the most effective application of AFFF.

In 1968 the Navy conducted full-scale fire test studies (Reference 3) at the Naval Air Station (NAS), Jacksonville, to evaluate a new sea water-compatible AFFF for shipboard use. One of the test phases was designed to compare the application of AFFF through air-aspirating and non air-aspirating (adjustable water spray) type handline nozzles on 3500-square-foot JP-5 spill fires. It was found that fire control and extinguishing effectiveness increased, varying from 20 to 100 percent (depending on wind conditions), when AFFF was applied with the non air-aspirating nozzle. The inherent advantage of an adjustable pattern nozzle and the increased stream range for the more fluid foam produced were reported as contributing factors.

During the Air Force C-5A fire test program conducted at the Naval Weapons Center, China Lake (NWC/CL) in 1972, it was found (References 4 and 5) that large fires (4000 square feet to 48,000 square feet in area) reduced the effective discharge range and trajectory of turret nozzles. Greater fire penetration and extinguishing effectiveness was achieved when AFFF was applied through water barrel turret nozzles, but an unmeasured reduction in burnback resistance was also observed.

Based on the above-mentioned test results and more recent comparative nozzle tests on large-scale fires conducted by the Navy at NWC/CL in 1975, variable-pattern water nozzles for applying AFFF were chosen for installation on the new Navy P-4A crash rescue and fire fighting vehicle.

COMPARATIVE NOZZLE STUDY

Aqueous film forming foam has now replaced protein foam for aircraft crash rescue and fire fighting purposes at all military air activities. There is, however, no general agreement in the fire fighting community as to optimum foam characteristics or nozzle types to use for this application, indicating a need for further research in this field. This report covers a comparative nozzle study for applying AFFF conducted by the Naval Research Laboratory and sponsored by Detachment 1 (Civil and Environmental Engineering Development Office), Armament Development and Test Center (ADTC). Some of the fire tests were performed at the Naval Weapons Center.

The turret or handline nozzles currently used are classified as being either of the air-aspirating or non air-aspirating type. These nozzles have the following characteristics:

Air-Aspirating Device

- Is a specially designed foam nozzle, originally developed for use with protein foam.
- Has air-inlet ports at the base of a long, enclosed air/foam solution mixing barrel.
- Has stream-shaping devices for pattern variation.
- Produces expanded, relatively viscous, expansion 6-12 aqueous film forming foams.

Non Air-Aspirating Device

- Is a conventional variable pattern water nozzle.
- Has no attached mixing barrel.
- May have external impinging orifices in center section to provide full spray pattern.
- Discharges aqueous film forming foam solution and entrains air while in flight.
- Produces fluid, expansion 2-10 aqueous film forming foams.

The large-scale test program described herein was conducted at the Naval Weapons Center during January 1977.

SECTION II

TEST OBJECTIVES AND PHASES

The overall test objective was to determine the quantitative advantages and disadvantages of applying aqueous film forming foams through conventional water spray nozzles as compared to foam barrel nozzles. Commercially available nozzles were to be tested and evaluated. Influencing factors, such as fire control, foam quality, pattern characteristics, burnback resistance, application technique, and presence of aircraft mock-up were to be analyzed.

The fire test program was divided into two phases. Phase I was designed to determine the relative effectiveness of nozzles in the 250-gpm category, and Phase II was designed to determine relative effectiveness of nozzles in the 750 to 800 gpm category.

SECTION III

TEST ARRANGEMENTS AND PROCEDURES

TEST SITE

For this test program, a section of the test site originally constructed for the Air Force C-5A tests (Reference 4) was utilized. An overall view of the test site is shown in Figure 1. Phase I fire test areas were 4000 square feet in size, and Phase II test areas were 8000 square feet in size. A combination of three adjacent, 40-foot by 100-foot diked areas were used. Some of the tests involved the use of an obstacle which was placed in the area to the right, as depicted in Figure 2. The dimensions of the aircraft mock-up were: 6-foot diameter, 36 feet long, with an 18-foot wing span, and an overall 8-foot height. Each area had been recessed in the sandy soil and provided with a crushed rock base. Prior to fueling, a sufficient amount of water was added, as shown in Figure 3, to ensure a level surface for full area fire involvement. Figure 4 shows two adjacent areas covered with water prior to fueling.

As illustrated in Figure 5, the area along the 100-foot side of the test-bed was striped at 10-foot intervals to aid test personnel in obtaining fire extinguishment and burnback test data.

VEHICLES

The crash vehicles used as test nozzle beds are depicted in Figure 6. The Navy MB-1 vehicle, on the left in Figure 6, was used for all Phase I tests. The Air Force P-4 vehicle, in the center in Figure 6, and the Navy P-4A vehicle, on the right in Figure 6, were used for all Phase II tests. The MB-1 and P-4A vehicles were stationed at the Naval Weapons Center. The

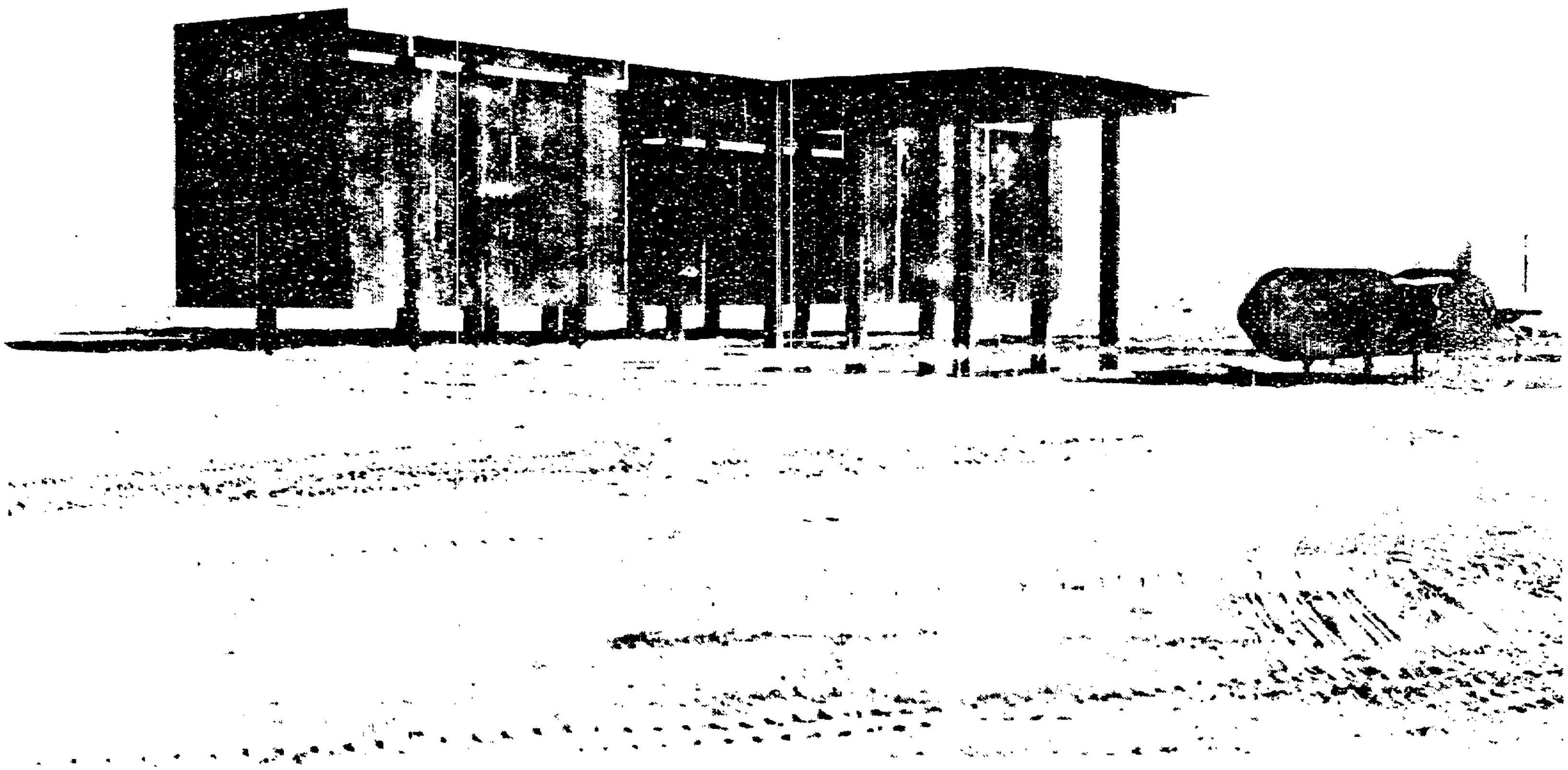


Figure 1. Overall View of Fire Test Site — C-5A (Mock-up is in Background.)

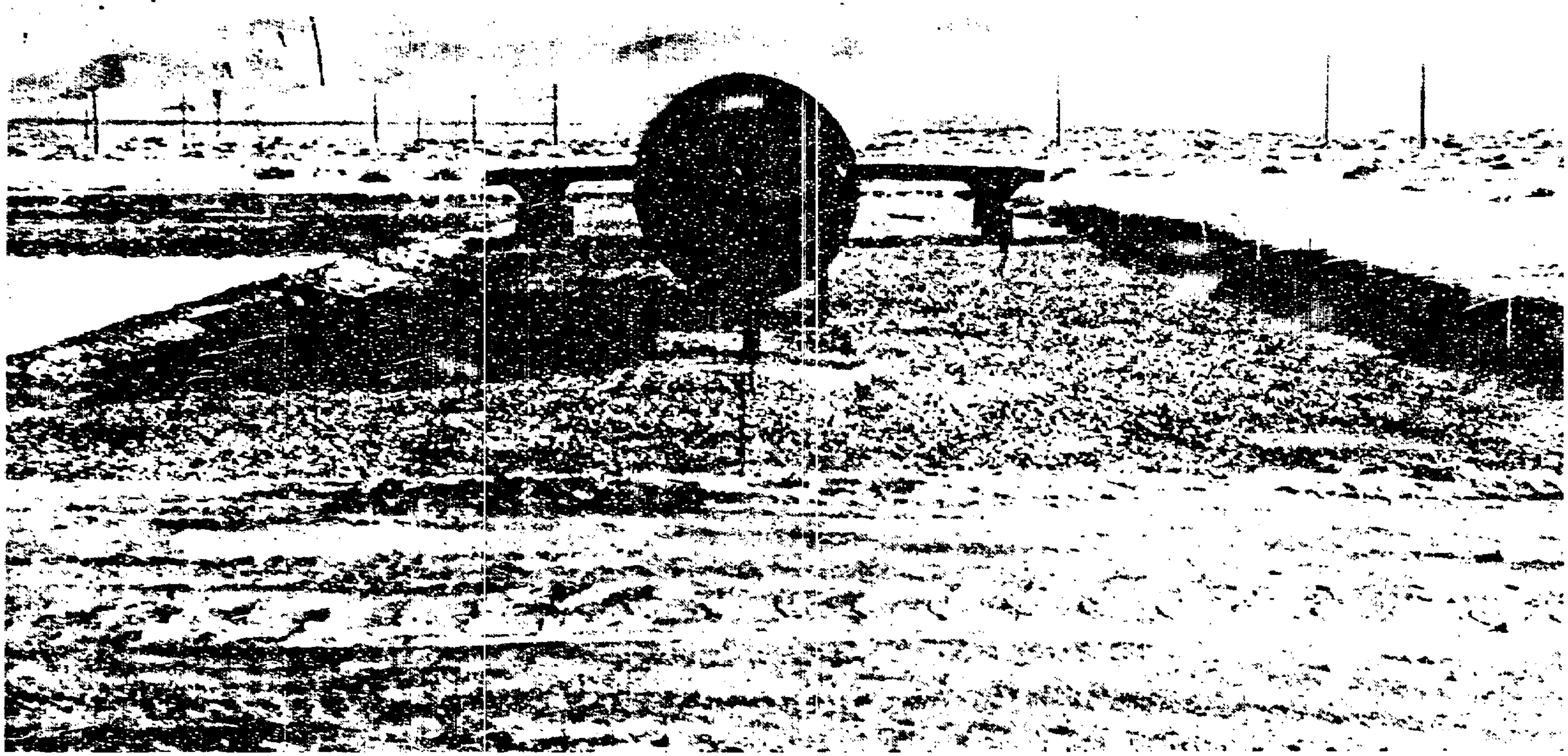


Figure 2. 4000 ft^2 (40 x 100 feet) Fire Test Area with Crushed Rock Base and Aircraft Mock-Up

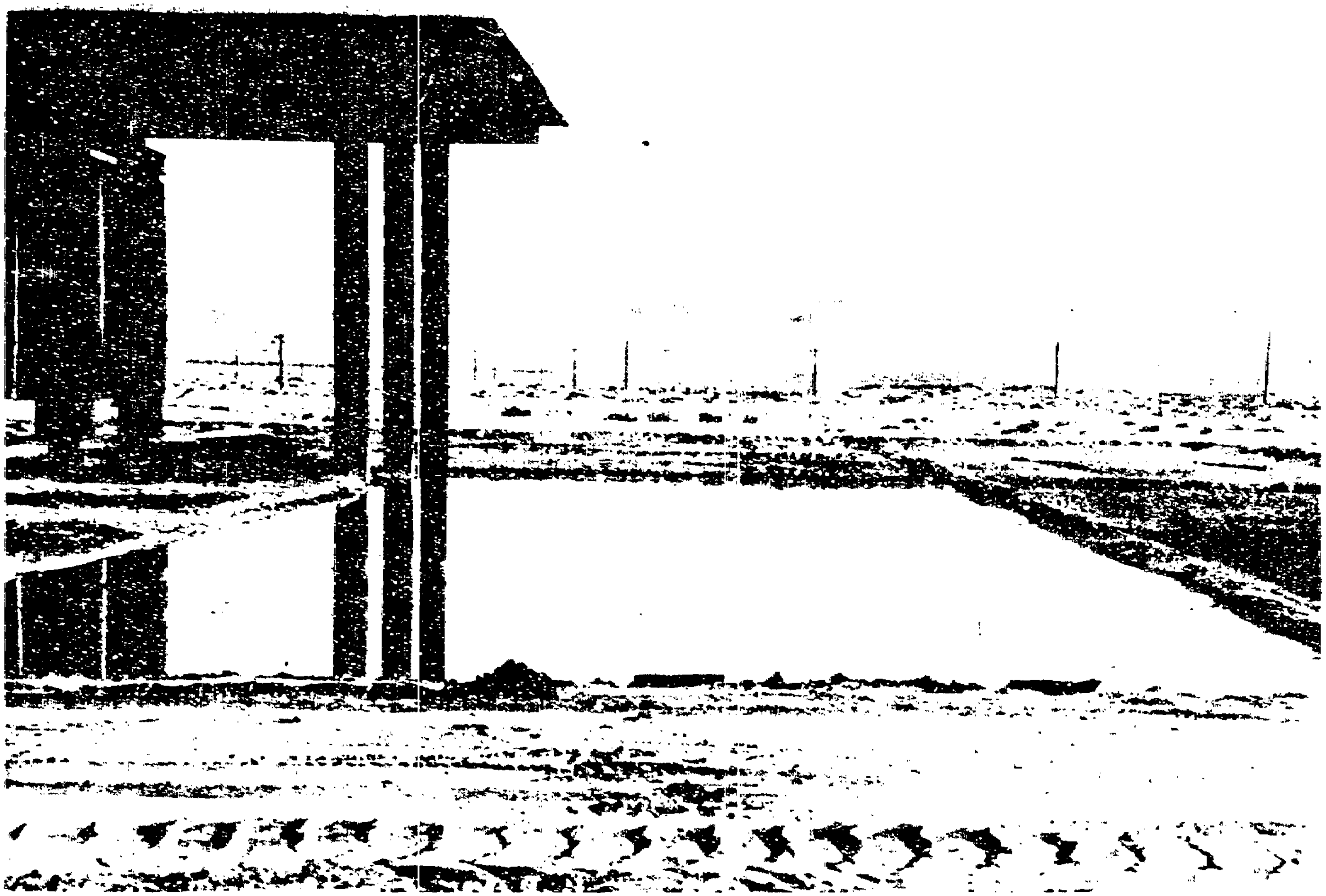


Figure 3. 4000 ft^2 Fire Test Area with Water Cover Prior to JP-4 Fueling

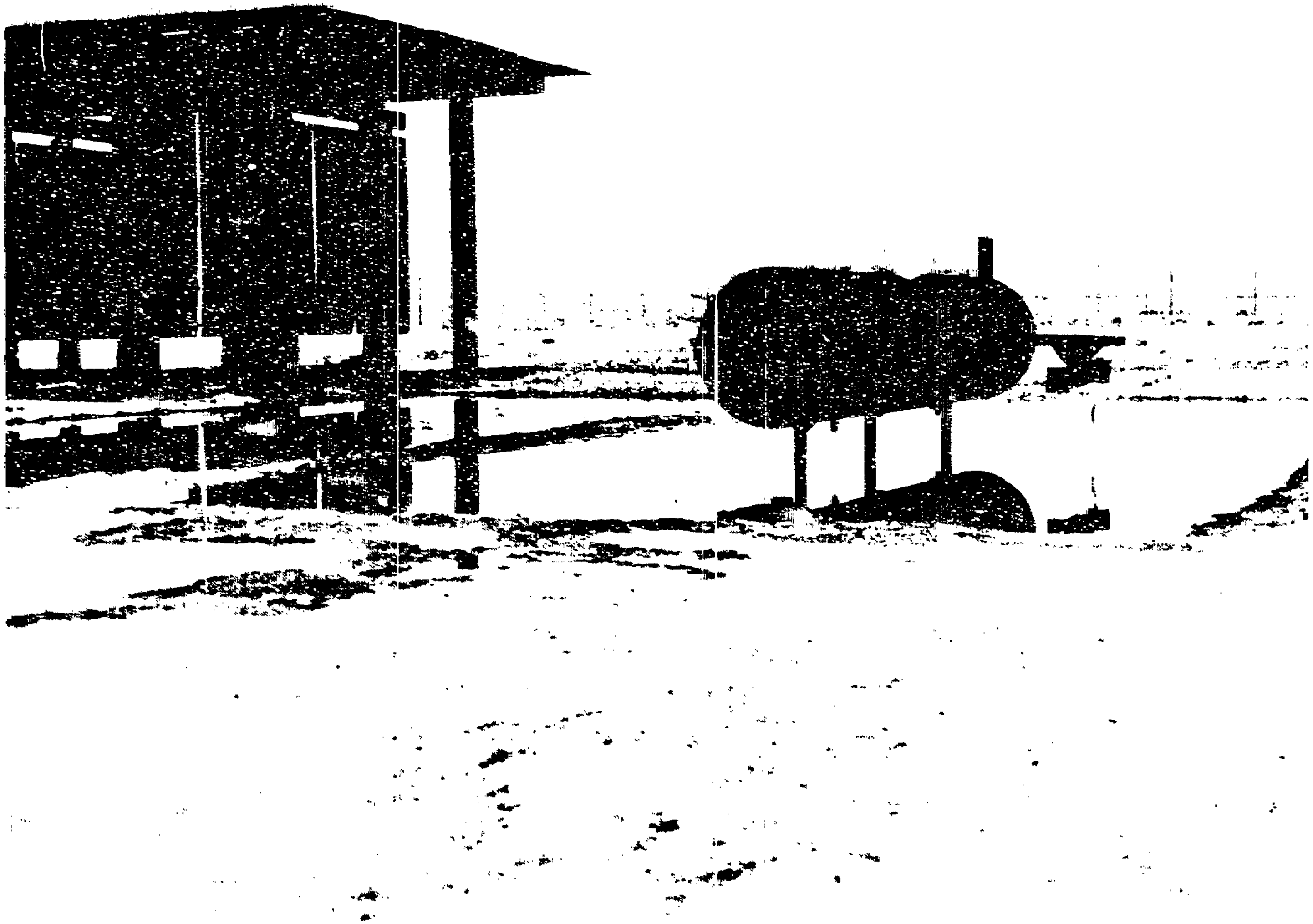


Figure 4. 8000 ft^2 Fire Test Area, Consisting of Two Adjacent 40 x 100 Foot Areas, With Aircraft Mock-Up

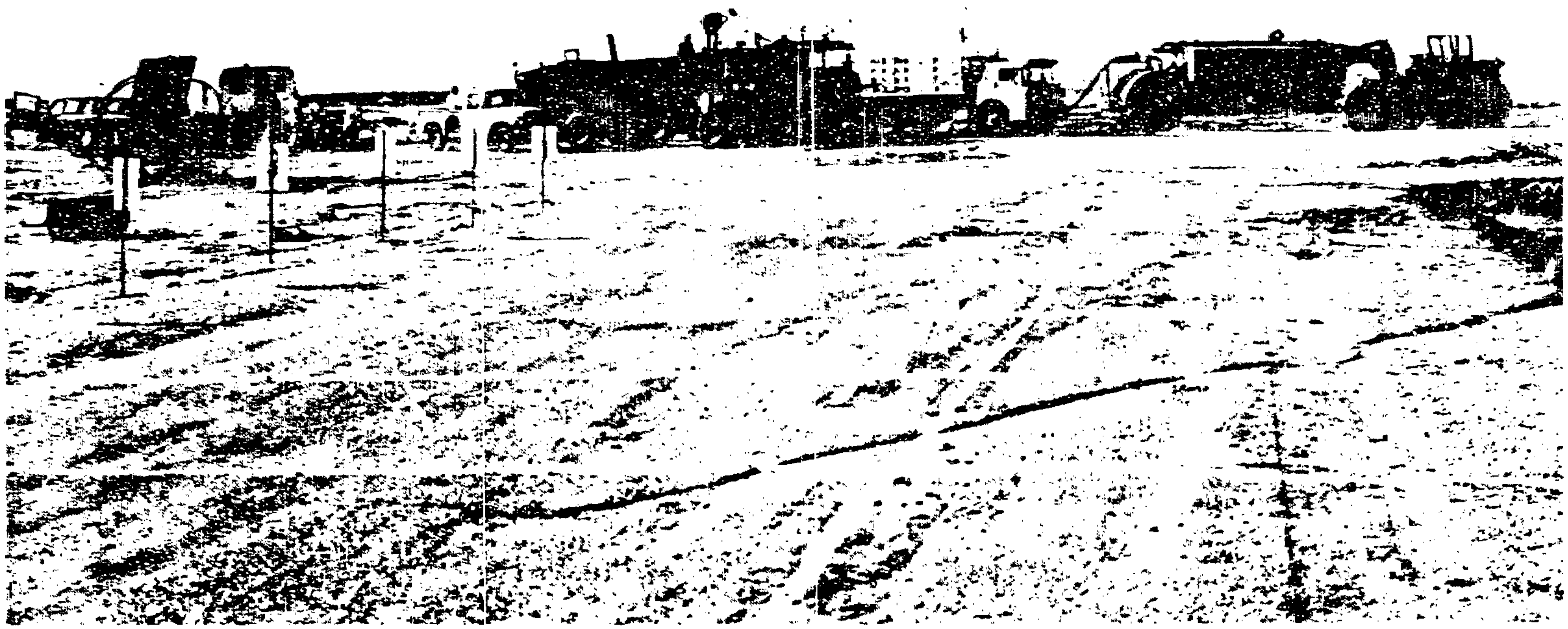


Figure 5. Ground Stripes, 10 Feet Apart, Along 100 Foot Side of Fire Test Area

Figure 6. Aircraft Rescue and Fire Fighting Vehicles Used in Fire Tests. Left, Navy MB-1; Center, Air Force P-4; Right, Navy P-4A

same turret operator was employed for tests involving both of these vehicles. The P-4 vehicle with an operating crew was provided by Edwards Air Force Base.

In order to verify nozzle flow rates for each test, the water tanks of these vehicles were calibrated in gallons per inch with the following results: MB-1, 23.3 gallons per inch; P-4 and P-4A, 36.6 gallons per inch. The proportioning of AFFF concentrate was determined by using the refractometric method and also by metering the amount of AFFF concentrate needed to refill the concentrate tank after each test. AFFF proportioning was found to be within 1 percent of the desired 6 percent concentration.

NOZZLES

PHASE I TESTS

For the Phase I tests, a Rockwood foam barrel turret, as shown in Figure 7, was used as the air-aspirating-type nozzle. Figure 8 illustrates the Model DSF Elkhart nozzle used as the non air-aspirating device. Both nozzles had a discharge rate of 250-gpm at 200 psi nozzle pressure and were manually operated.

PHASE II TESTS

For Phase II tests, a Feecon, double-barrel foam turret, shown in Figure 9, served as the air-aspirating-type nozzle. It is flow-rated at 800-gpm for 240 psi pump pressure. This nozzle was remotely controlled from the cab of the P-4 vehicle. Figure 10 shows the non air-aspirating, Elkhart/Feecon turret nozzle which was manually operated from the roof of the P-4A vehicle. It is a nominal 750-gpm nozzle. For this application, it was flow-tested at 787-gpm for 125 psi nozzle pressure.

All the test nozzles were flow-tested based on the water tank calibrations previously obtained for each vehicle. Under these test conditions, all nozzles flowed at their rated

Figure 7. 250 gpm Air-Aspirating Turret Nozzle on MB-1 Vehicle

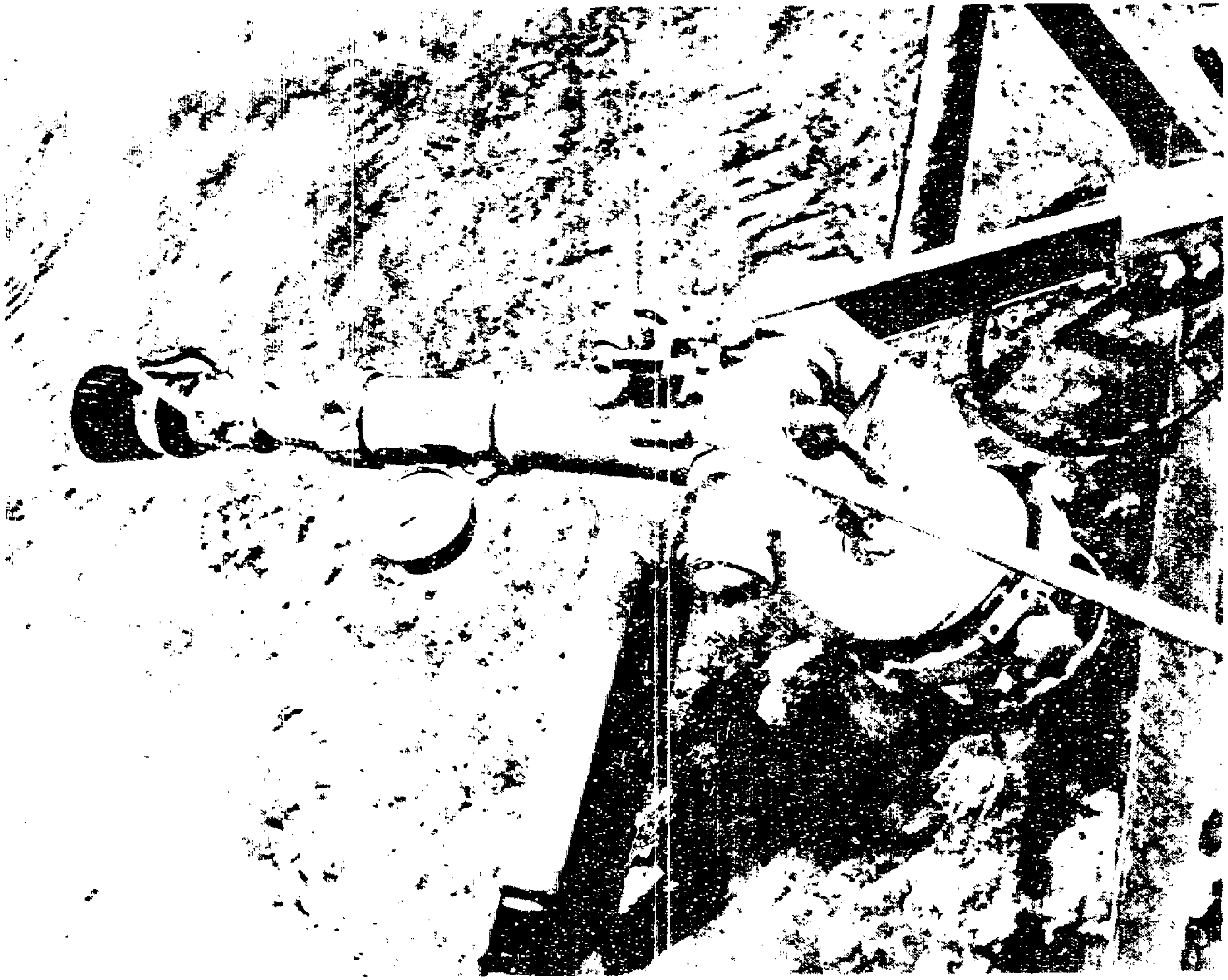


Figure 8. 250 gpm Air-Aspirating Turret Nozzle on MB-1 Vehicle

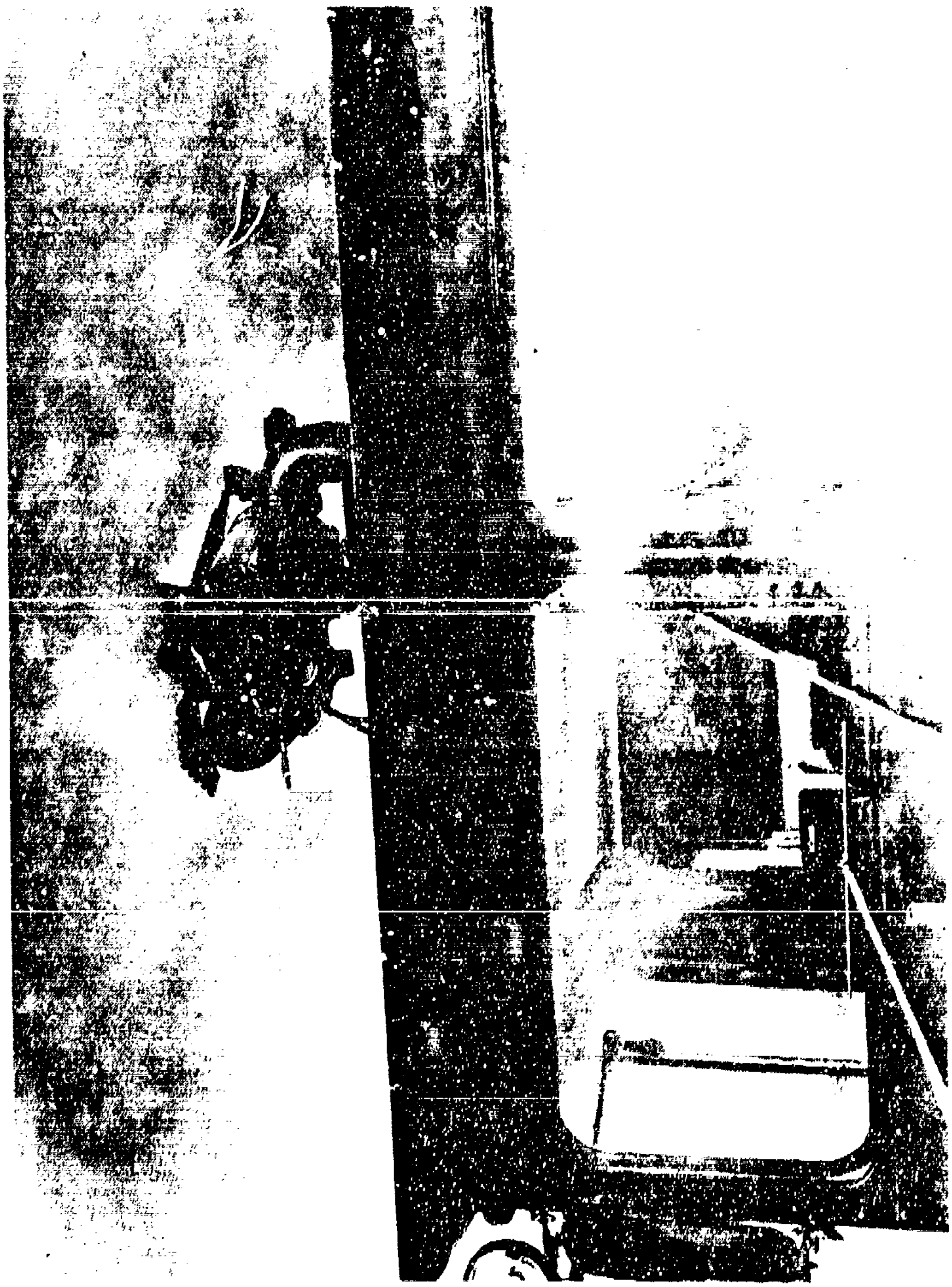


Figure 9. 800 gpm Air-Aspirating Turret Nozzle on P-4 Vehicle

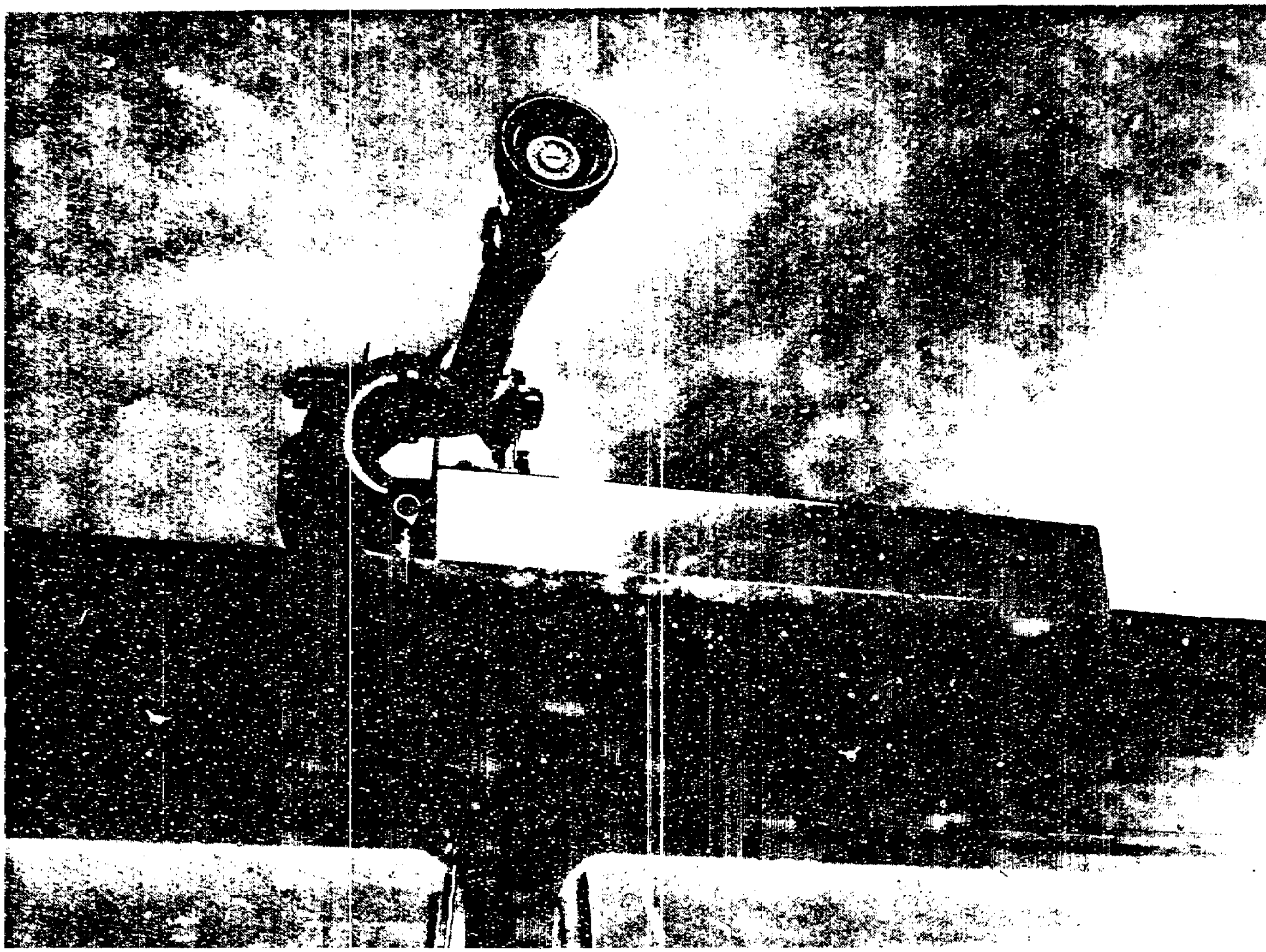


Figure 10. 750 gpm Non Air-Aspirating Turret Nozzle on P-4A Vehicle

capacity except for the Feecon 800-gpm nozzle. After engine governor adjustments were made, the highest water flow rate obtained was 750-gpm.

The pattern characteristics and analyses of aqueous film forming foam produced by these turret nozzles were made in accordance with the procedures of the National Fire Protection Association Pamphlet 412 (Reference 6). The test results are summarized in Table 1.

MATERIALS

The AFFF concentrate used in all the tests was FC-206, Lot 60, and met Military Specification, MIL-F-24385 (Reference 7).

JP-4 was used as the test fuel for all tests. For the Phase I tests, 1000 gallons were utilized for each test, and 2000 gallons were utilized for each Phase II test. These quantities were employed to prevent premature burnout and represented approximately 0.4-inch fuel depth, providing about 3 minutes of full area burning time.

During the testing period, the temperature of the water used varied from 58° to 66°F, while the fuel and air temperatures ranged from 38° to 58°F and from 37° to 68°F, respectively. Ambient wind speeds varied from 1 to 7 knots and were generally from a southerly direction, which was considered ideal for the test site location.

DATA RECORDING

Helmets equipped with radio headsets were furnished to experienced fire test observers for communication and data recording purposes. Stop watches were used for timing the sequence of events. The test director relayed pertinent data to another observer for recording purposes. Two other observers served as timers to record data separately. At the conclusion of each fire test, recorded data was compared to ensure an accurate determination of test events.

TABLE 1. TURRET - AQUEOUS FILM FORMING FOAM: ANALYSIS AND PATTERN CHARACTERISTICS

	MB-1 250-GPM AIR-ASPIRATING TURRET		MB-1 250-GPM NON AIR-ASPIRATING TURRET		P-4 800-GPM AIR-ASPIRATING TURRET		P-4A 750-GPM NON AIR-ASPIRATING TURRET	
	PATTERN		PATTERN		PATTERN		PATTERN	
	Full Spray	Straight Stream	Full Spray	Straight Stream	Full Spray	Straight Stream	Full Spray	Straight Stream
EXPANSION	4.3	6.0	1.9	3.1	7.7	9.9	4.1	8.4
25 PERCENT DRAINAGE TIME (MIN)	5.4	5.1	2.4	4.2	5.8	5.8	2.7	3.3
REACH (FT)	63	120	67	188	110	175	114	213

PHOTOGRAPHIC COVERAGE

Figure 11 shows the 16 mm motion picture camera located on an elevated scissors-bed platform which took continuous color film footage of each fire test. This footage was used to verify test data and study operator technique. Several still cameras were employed to photograph test arrangements and burn-back test sequences.

FIRE TEST PROCEDURES

For both Phases I and II, duplicate fire tests were run on an alternate basis, with and without the aircraft mock-up. A total of 16 fire tests were conducted.

The JP-4 fuel was ignited with a flare gun and given approximately a 30-second preburn time. During this period, the test vehicle was driven to a predetermined, marked spot, 15 feet from the leading edge of the test area. The turret operators were instructed to start the initial fire attack with full-spray foam patterns in an oscillating manner and then gradually narrow the foam pattern to achieve the test criterion of fire control (90-percent extinguishment). The initial attack, full-spray patterns, for the air-aspirating and non air-aspirating foam nozzles used in the Phase I tests, are depicted in Figures 12 and 13 respectively. Similarly, for the Phase II tests, Figures 14 and 15 show the initial fire attack patterns of the air-aspirating and non air-aspirating foam nozzles, respectively.

After 90 percent control had been established, foam application was continued to the point of complete or almost complete extinguishment. The total foam application time was held constant in order to provide an equal starting point for the burnback evaluation which followed. In the event complete extinguishment was not effected at the conclusion of foam application, any lingering berm fires were gently extinguished by means of portable dry chemical units. Figure 16 shows a typical AFFF foam blanket appearance immediately after fire extinguishment.

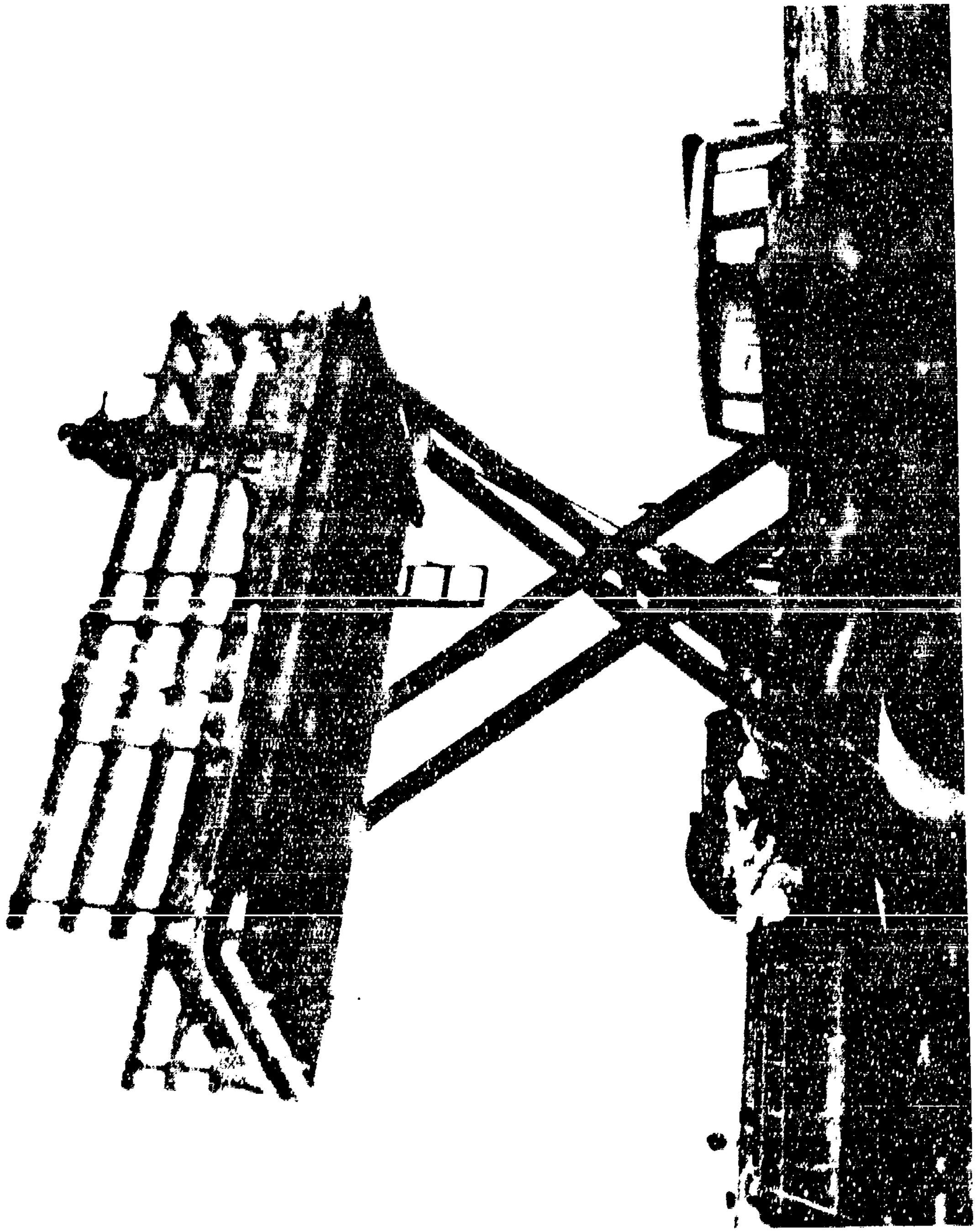


Figure 11. 16mm Motion Picture Camera on Elevated, Scissors-Bed Platform

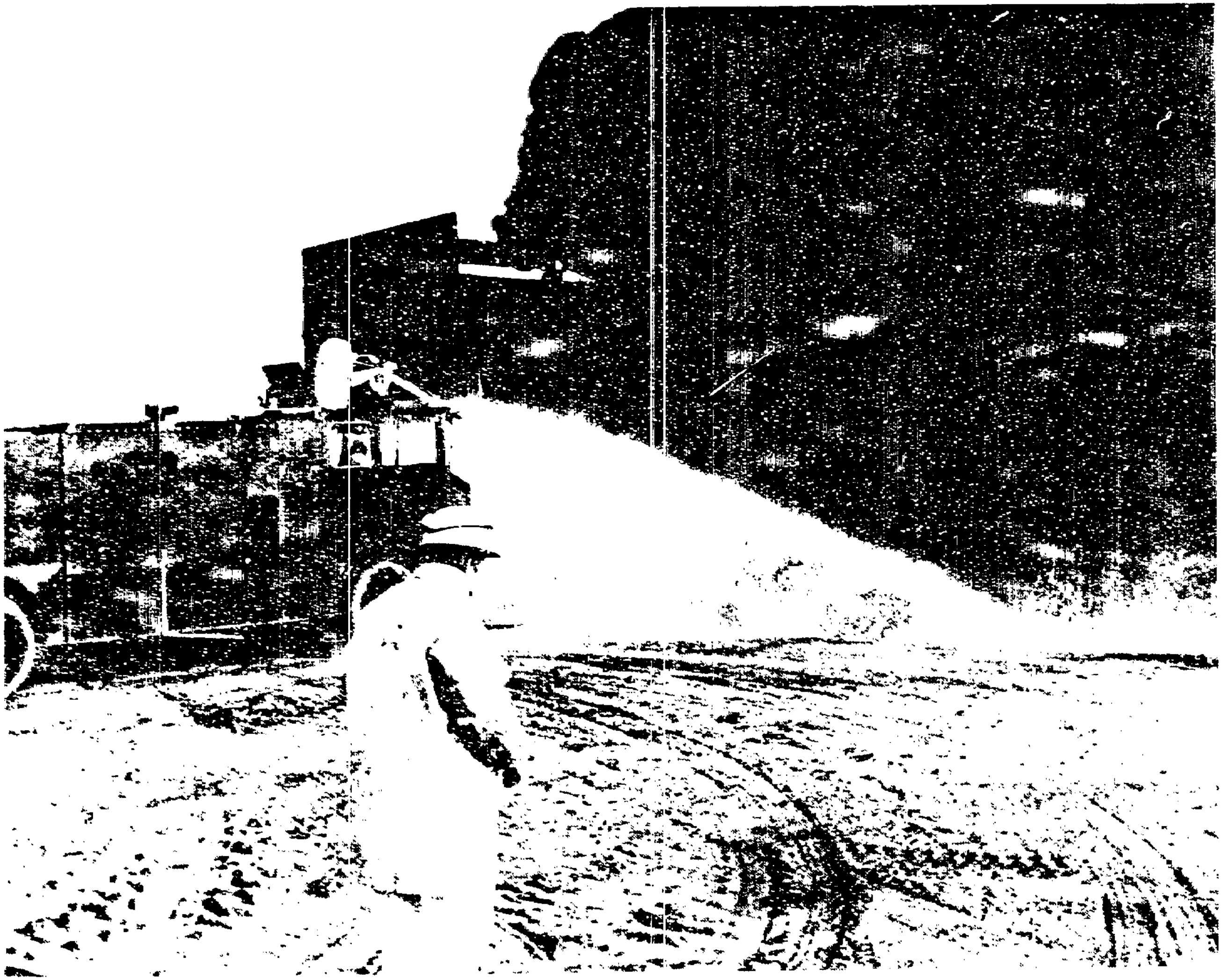


Figure 12. Typical AFFF Spray Pattern Application for 250 gpm Air-Aspirating Turret Nozzle on 4000 ft^2 Fire Test Area

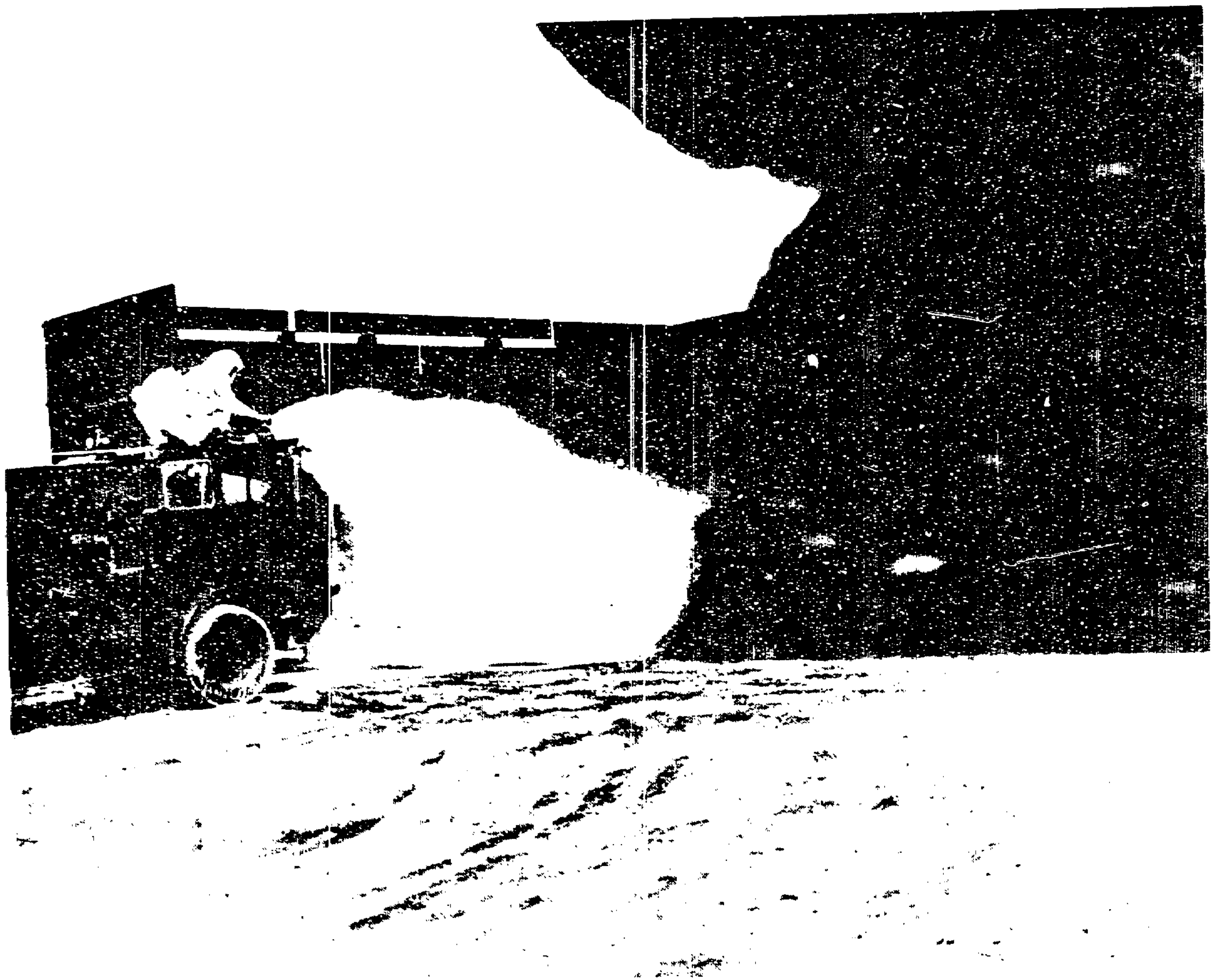


Figure 13. Typical AFFF Spray Pattern Application for 250 gpm Non Air-Aspirating Turret Nozzle on 4000 ft^2 Fire

Figure 14. Typical AFFF Spray Pattern Application for 800 gpm Air-Aspirating Turret Nozzle on 8000 Ft^2 Fire

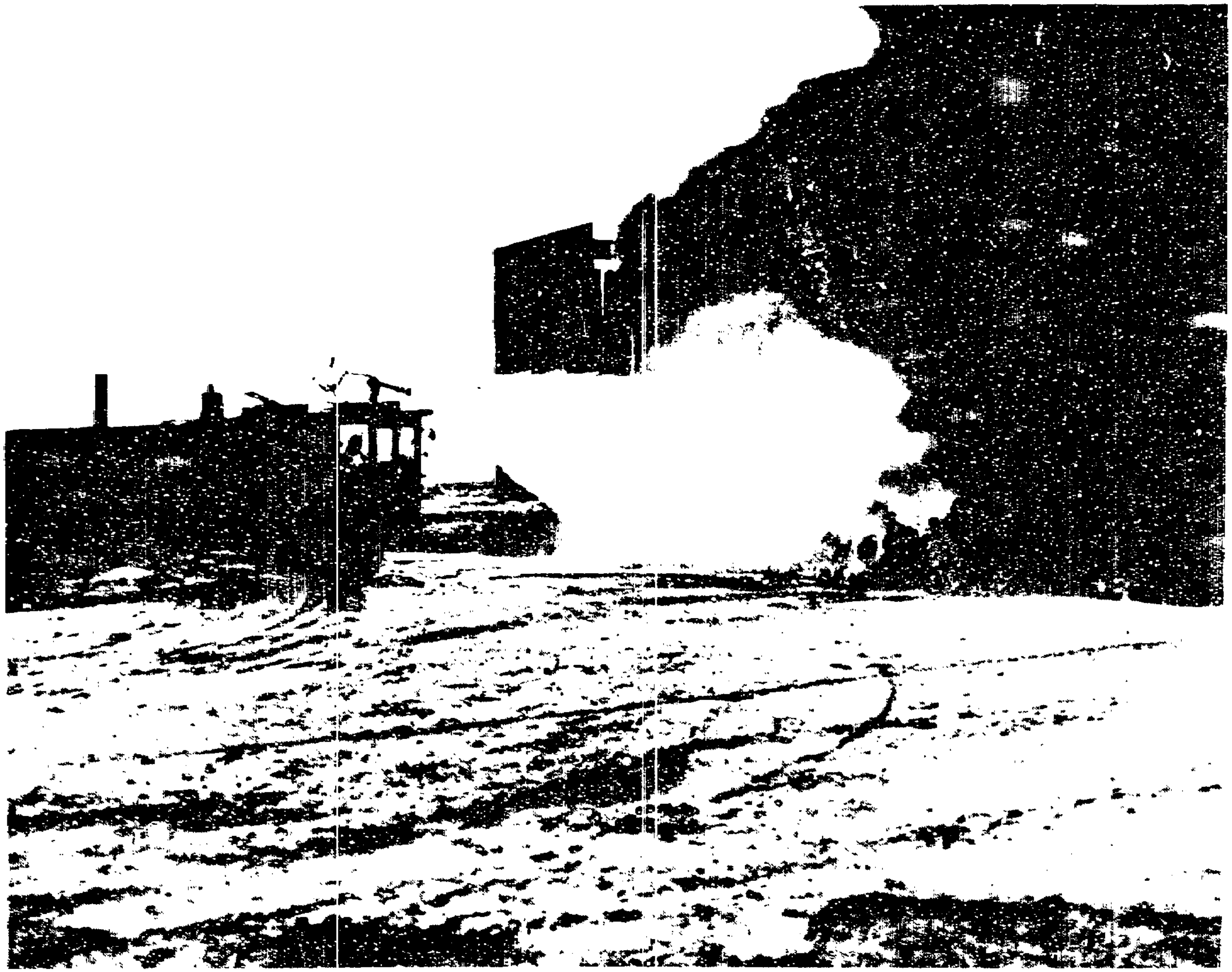


Figure 15. Typical AFFF Spray Pattern Application for 750 gpm Non Air-Aspirating Turret Nozzle on 8000 Foot^2 Fire

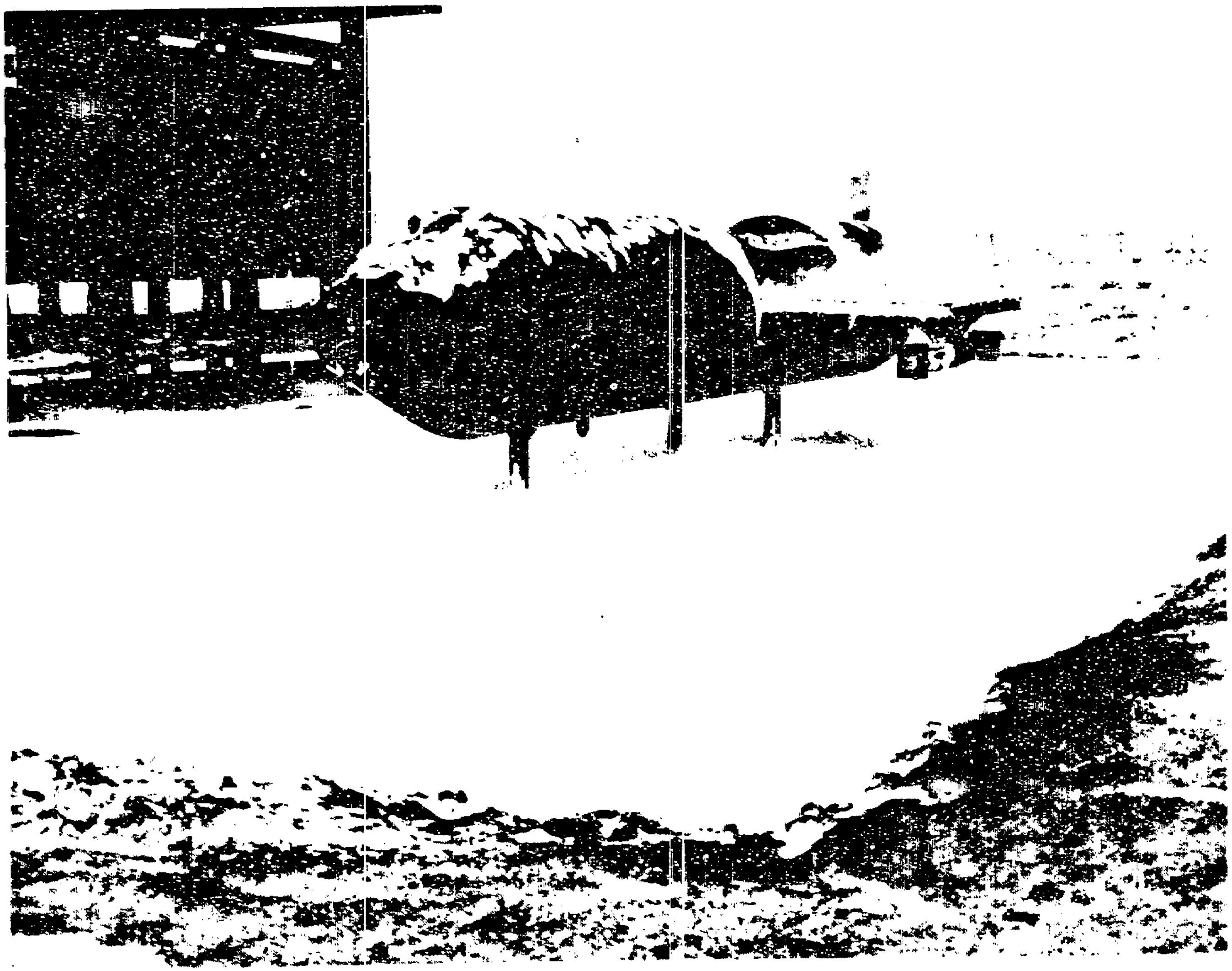


Figure 16. Typical AFFF Foam Blanket on 4000 Foot^2 Area — Immediately After Fire Extinguishment

BURNBACK TEST PROCEDURES

Figure 17 illustrates the start of the burnback test procedure followed after each fire extinguishment. The procedure commenced within 7 to 8 minutes after extinguishment. Prior to placement of the 12-inch-diameter burnback pan 8 feet inside the test area, it was fueled with about a 1-inch depth of motor gasoline. The rate of fire enlargement was recorded and the time to achieve reburning over 25 percent of the total area was used as the test criterion.

a. Positioning Burnback Pan Inside Test Area

b. Torching Fuel in Burnback Pan and
Start of Clock for Timing Burnback

c. Removal of Burnback Pan After Sustained Ignition of
JP-4 Fuel Occurred Outside of Pan Approximately 5 Minutes

Figure 17. Typical Burnback Test Procedure

SECTION IV

TEST RESULTS AND DISCUSSION

PHASE I TESTS

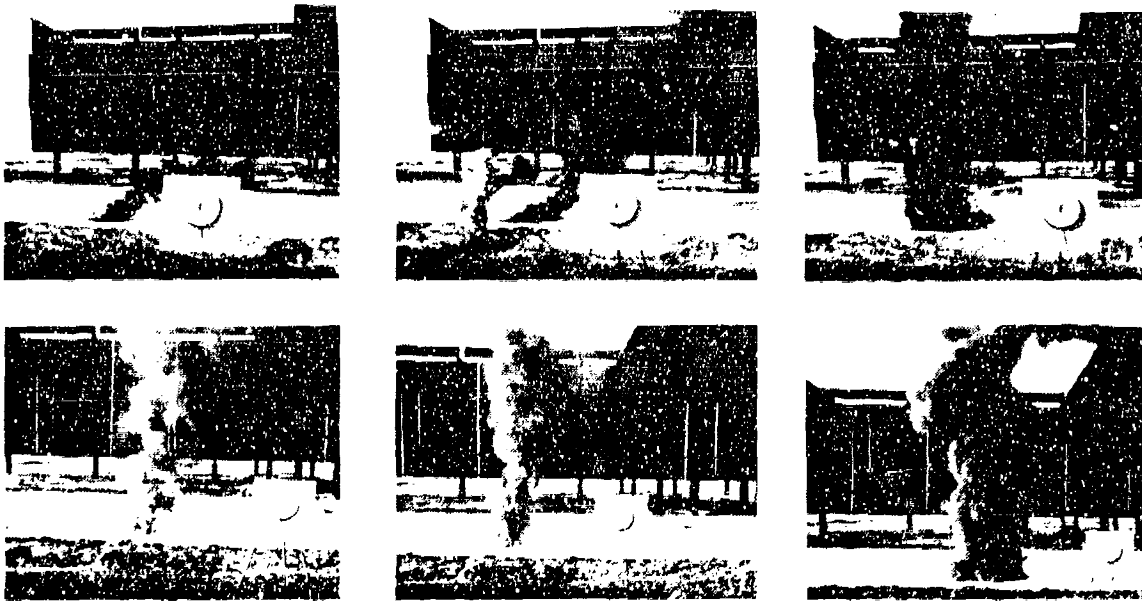
The results of the eight fire tests conducted for the Phase I test series are summarized in Table 2. Duplicate fire tests, although run alternately to increase validity of test results, are presented successively to facilitate comparison. Analysis of 90-percent fire control times obtained reveal that AFFF applied through the non air-aspirating nozzle achieved control in approximately two-thirds the time required for the air-aspirating nozzle, either with or without the presence of the aircraft mock-up. The superior performance of the non air-aspirating nozzle is attributed to the increased fluidity provided by the low-expansion foams produced and also the advantage of stream range (see Table 1). The aircraft mock-up did not influence the performance of either nozzle.

Operator technique used in applying aqueous film forming foam from both types of nozzles was commendable. The duplication of control times within a margin of 10 percent as shown in Table 2, is well within the deviation normally experienced for fire tests of this magnitude.

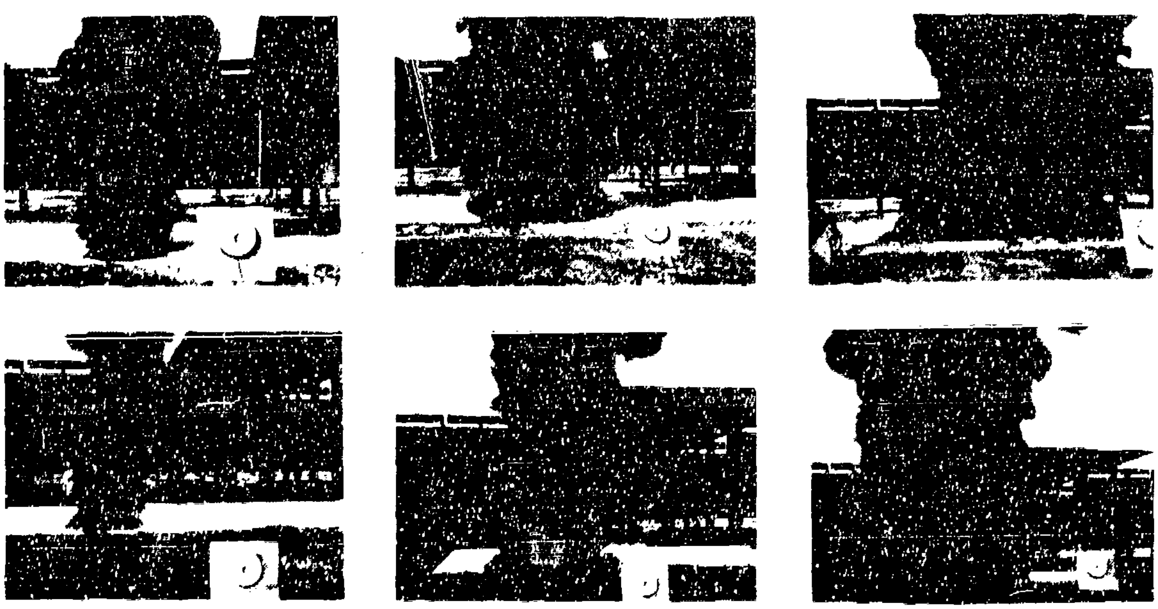
Analysis of the 25 percent burnback time data (Table 2) yields no definite trend of superiority for the aqueous film forming foams produced with either type of nozzle. However, it should be pointed out that the rate of burnback is subject to many factors, such as agent application density, types of fuel, wind, substrate, and location of burnback pan. For these comparative tests, the agent application densities were held similarly. Wind speeds were generally low, ranging from 0 to 2 knots, and the burnback pan was placed toward the downwind side. Figure 18 shows typical stages of burnback for air-aspirated

TABLE 2. SUMMARY OF PHASE I FIRE TEST DATA FOR APPLYING AQUEOUS FILM FORMING FOAM FROM 250-GPM AIR-ASPIRATING AND NON AIR-ASPIRATING NOZZLES (MB-1 VEHICLE) ON 4000 SQUARE FOOT JP-4 FUEL FIRES

				FIRE CONTROL 90% EXTINGUISHMENT		BURNBACK	
TEST NO.	AIRCRAFT MOCK-UP	NOZZLE	AFFF SOLUTION RATE (gpm)	TIME (sec)	APPLICATION DENSITY (gal/ft^2)	TIME TO 25% (min)	APPLICATION DENSITY (gal/ft^2)
1	NO	AIR-ASP	260	31	0.033	12.3	0.059
3	NO	AIR-ASP	267	28	0.031	16.6	0.063
2	NO	NON AIR-ASP	263	22	0.024	11.2	0.063
4	NO	NON AIR-ASP	241	18	0.018	14.0	0.055
5	YES	AIR-ASP	252	27	0.028	11.7	0.058
7	YES	AIR-ASP	239	31	0.031	13.8	0.059
6	YES	NON AIR-ASP	240	23	0.023	21.0	0.056
8	YES	NON AIR-ASP	232	21	0.020	17.7	0.056



a. AFFF Burnback at 3 Minutes   b. AFFF Burnback at 5 Minutes   c. AFFF Burnback at 6 Minutes



d. AFFF Burnback at 7 Minutes   e. AFFF Burnback at 10 Minutes   f. 25% AFFF Burnback at 12 Minutes

Figure 18. Typical Stages of Burnback for Air-Aspirated AFFF (Test 1) – TOP of Split-View and Non Air-Aspirated AFFF (Test 2) – BOTTOM of Split-view

AFFF (Test 1) and non air-aspirated AFFF (Test 2) resulting in similar 25-percent burnback times. The presence of the aircraft mock-up for Tests 5 to 8 had no discernible effect on the 25-percent burnback times.

PHASE II TESTS

The results of the eight fire tests conducted for the Phase II test series are summarized in Table 3. The data are presented as in Table 2 with one exception -- Tests 14 and 15 were run consecutively but on different days. Again, as found in the Phase I tests, the fire control times obtained when applying AFFF through the non air-aspirating nozzle were two-thirds of those for the air-aspirating nozzle for both test conditions, with and without the aircraft mock-up. Data from Test 10 are not included in this analysis because of an equipment malfunction, resulting in the application of water-only for the first 20 seconds.

Earlier in this report it was noted that preliminary flow testing of the air-aspirating nozzle on the P-4 vehicle indicated roughly a 10 percent decrease in its rated capacity of 800-gpm. For these fire tests (Table 3), the average flow rate for this nozzle was 710-gpm compared to 820-gpm (13 percent higher) for the non air-aspirated nozzle on the P-4A vehicle. However, these differences in flow rates were equilibrated by comparing the actual application densities (not time) required for each nozzle to achieve fire control. On this basis, these data, excluding Test 10, still show it required only two-thirds the amount for the non-aspirating versus the aspirating.

The comments made concerning the superior performance of the non air-aspirating nozzle for the Phase I tests also apply here for the Phase II tests. The data for aqueous film forming foam analysis and pattern characteristics for each nozzle are

TABLE 3. SUMMARY OF PHASE II FIRE TEST DATA FOR APPLYING AQUEOUS FILM FORMING FOAM FROM 750 to 800-GPM AIR-ASPIRATING AND NON AIR-ASPIRATING NOZZLES ON 8000 SQUARE-FOOT JP-4 FUEL FIRES

					FIRE CONTROL (90% EXTINGUISHMENT)		BURNBACK	
TEST NO.	AIRCRAFT MOCK-UP	TEST VEHICLE	NOZZLE	AFFF SOLUTION RATE-gpm	TIME (sec)	APPLICATION DENSITY (gal/ft^2)	TIME TO 25% (min)	APPLICATION DENSITY (gal/ft^2)
9	NO	P-4	AIR-ASP	711	37	0.055	15.5	0.121
11	NO	P-4	AIR-ASP	671	39	0.055	21.0	0.095
10	NO	P-4A	NON AIR-ASP	819	40*	0.068*	14.0	0.128
12	NO	P-4A	NON AIR-ASP	804	27	0.045	18.0	0.116
13	YES	P-4	AIR-ASP	715	35	0.052	14.3	0.090
16	YES	P-4	AIR-ASP	739	34	0.052	12.8	0.120
14	YES	P-4A	NON AIR-ASP	823	23	0.039	>28**	0.105
15	YES	P-4A	NON AIR-ASP	840	23	0.040	16.5	0.107

*Equipment malfunction - water only for initial 20-second application
**Wind conditions affected test results

included in Table 1. The turret operators generally followed the technique outlined in the test plan for gaining control of these fires. However, during several tests with the air-aspirating nozzle, it was observed that the turret operator's vision was overly obscured because of his remote position inside the cab of the P-4 vehicle. For example, during Test 13, the turret operator did not see the fire remaining beyond the aircraft mock-up and inadvertently shut off the turret twice before final extinguishment was achieved. The more pronounced effect of the influence of large-scale fires and crosswinds on the effective range of air-aspirating nozzles was observed during the conduct of Test 16. With a crosswind of 7 knots, difficulty was experienced in reaching the far edge of the test fire which was 115 feet distant from the turret. Table 1 shows a straight stream reach of 175 feet for this air-aspirating nozzle under no-fire test conditions and without a crosswind.

The burnback test data in Table 3 show relatively equal performance for both types of aqueous film forming foams produced. The aircraft mock-up did not appear to be a factor. These results are similar to the Phase I test data given in Table 2. The data for Test 14 was favorably influenced by an increase in wind speed which carried the flames away from the foam blanket and outside the test area. After 28 minutes, only 100 square feet (<2 percent) of the total area was afire, and no further data was recorded, since it was obvious that most of the exposed fuel had been consumed. Conversely, a wind shift across the test area would have been detrimental to burnback since the smooth surface provided by the water substrate permits the AFFF blanket to readily slide around.

SECTION V

CONCLUSIONS

Non air-aspirating nozzles provide longer reach streams than air-aspirating nozzles under both fire and non-fire conditions. Crosswinds and large-scale fires adversely affect stream reach for both types of nozzles.

There is no advantage in using air-aspirated nozzles for dispensing AFFF. In fact, air-aspirated foams required approximately 50 percent longer to achieve control than the lower expansion, more fluid, non air-aspirated foams.

Well-applied AFFF from a single, fixed turret location at 0.06 gallons per minute/square foot should afford 90 percent fire control within 30 seconds over a relatively non-obstructed area within turret reach. The aircraft mock-up, as used, was not a factor in time required for achieving control of the fire or in burnback.

The burnback resistances of both types of aqueous film forming foams produced are considered relatively equal for the test conditions used. This was true even though the aspirated foam blanket at the end of the application period was much thicker and looked as if it would be much more resistant to burnback than the non-aspirated foam.

Operator technique is definitely a factor in achieving fire control. Aqueous film forming foam can best be applied by continually sweeping the entire fire area, changing patterns as needed to avoid overkill and waste of agent.

SECTION VI
RECOMMENDATIONS

It is recommended that consideration be given to utilizing manual turrets directed by operators looking over them and fitted with non air-aspirating-type AFFF nozzles on all aircraft crash rescue and fire fighting vehicles. These nozzles should be easier to maintain and lower in cost.

It is also recommended that further improvement in nozzle design for the application of aqueous film forming foam be sought from nozzle manufacturers and workers in this field.

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