FIELD TEST OF WARM FOG DISPERSAL SYSTEM TO SUPPORT MARINE CORPS HELICOPTER OPERATIONS

Robert D. Leipold

Sierra Research Corporation

Prepared for:

Marine Corps

20 June 1972

FIELD TEST OF

WARM FOG DISPERSAL SYSTEM TO SUPPORT

USMC HELICOPTER OPERATIONS

Project Officer
Robert D. Leipold, Lt Colonel, USMC

Contract No. M00264-72-C-0094

20 June 1972

Prepared for:
United States Marine Corps
Development and Education Center
Quantico, Virginia 22134

SIERRA
RESEARCH CORPORATION
ENVIRONMENTAL SYSTEMS GROUP
BOULDER, COLORADO

Unclassified
Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author)
Sierra Research Corporation
Environmental Systems Division
Boulder, Colorado 80303

2a. REPORT SECURITY CLASSIFICATION
Unclassified

2b. GROUP

3. REPORT TITLE
Field Test of Warm Fog Dispersal System to Support Marine Corps Helicopter Operations.

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)

5. AUTHOR(S) (First name, middle initial, last name)
Ralph Papania, Jr.

6. REPORT DATE
20 June 1972

7a. TOTAL NO. OF PAGES
75

7b. NO. OF REFS
5

8a. CONTRACT OR GRANT NO
M00264-72-C-0094

b. PROJECT NO

c.

d.

9a. ORIGINATOR'S REPORT NUMBER(S)

9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)

10. DISTRIBUTION STATEMENT
Distribution of this document is unlimited.

11. SUPPLEMENTARY NOTES
Details of illustrations in this document may be better studied on microfiche.

12. SPONSORING MILITARY ACTIVITY
United States Marine Corps
Development & Education Center
Quantico, Va., 22134

13. ABSTRACT
Warm fog dispersal techniques using helicopter downwash mixing and hygroscopic seeding were successfully tested to a limited degree on fog and low stratus. The equipment, procedures and nomograms for helicopter application of hygroscopic seeding materials are described as they were developed in three field tests. In August 1970 helicopter seeding apparatus and hygroscopic materials handling techniques were tested at Elmira Airport, N.Y. At Lewisburg, W. Va., August 1971, the clearing capability of 2 medium weight helicopters (CH-46 and H-3) were observed on 13 fog days. The last of the 3 tests was conducted at Cape Cod, 27 March to 21 April, 1972. During this test all ground support and airborne delivery tasks were performed by Marine Corps personnel. Weather conditions suitable for dispersal operations occurred on only one day, during which a useable clearing was created in low stratus, 650 feet thick.

Results show that the effectiveness of fog dispersal by helicopter downwash was considerably enhanced when the fog or stratus layer was treated with hygroscopic seeding agent (unsized urea in these particular tests). Some quantitative data and photographic coverage is presented. Additionally, helicopter pilots and Marine Corps observers unanimously concluded that seeded fog responded much better to the helicopter downwash technique than did the unseeded fog.

DD FORM 1 NOV 65 1473 (PAGE 1)

S/N 0101-807-6801

Unclassified
Security Classification

14 KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Fog Dispersal						
Helicopter fog clearing						
Hygroscopic seeding						
Weather modification						

FIELD TEST OF A WARM FOG DISPERSAL SYSTEM

TO SUPPORT

MARINE CORPS HELICOPTER OPERATIONS

Project Officer

Robert D. Leipold, Lt Colonel, USMC

Contract No. M00264-72-C-0094

20 June 1972

Prepared for:

United States Marine Corps

Development and Education Center

Quantico, Virginia 22134

Prepared by:

Ralph Papania, Jr.

-ic-

SIERRA

RESEARCH CORPORATION

ENVIRONMENTAL SYSTEMS GROUP

BOULDER, COLORADO

FORWARD

This report summarizes the results of a series of field experiments carried out by the Marine Corps Development Center to test warm fog modification techniques by use of helicopters and hygroscopic seeding materials. The program philosophy evolved around the need to develop equipment and techniques for the dispersal of warm fog to permit emergency resupply and medical evacuation in tactical areas during periods of fog or low stratus cloud cover. The experiments were conducted in three separate field tests: Quantico, Va., and Elmira, N. Y., August-September 1970; Lewisburg, W. Va., August 1971; and Otis AFB, Mass., April, 1972. Separate project reports were prepared for the 1970 and 1971 tests. This report covers the 1972 tests as well as a brief summary of the two previous tests.

TABLE OF CONTENTS

ILLUSTRATIONS

ILLUSTRATIONS (con'd)

1. INTRODUCTION

a. Program Objectives

(1) Purpose. This report describes a series of three field tests carried out in 1970, 1971, and 1972, by the Marine Corps Development Center and its contractor, Sierra Research Corporation. The purpose of the field tests was to examine the feasibility of using the combined effects of helicopter downwash mixing and hygroscopic seeding for the dispersal of warm fog. The general objectives of the tests were:

(a). Test the capability of hygroscopic seeding material, in combination with helicopter downwash, to produce operationally useful clearings in warm fog.

(b). Provide Marine Corps personnel with experience in operating airborne and ground support equipment associated with fog dispersal operations.

(c). Investigate the practical problems involved in applying the downwash seeding technique in forward operating areas.

(d). Establish preliminary tactics for the use of medium weight helicopters in warm fog dispersal operations.

(e). Collect meteorological and equipment performance data under actual fog conditions. Such data will be used to optimize the technique and to refine nomograms intended for tactical application of fog dispersal.

(2) Test Schedule. Tests were conducted in three progressive phases:

(a). August and September, 1970, Quantico, Va., and Elmira, N. Y.

This initial phase was designed to assemble, calibrate, and demonstrate the external seeding pod using the CH-46 helicopter and hygroscopic seeding powders.

(b). July and August, 1970, Lewisburg, W. Va.

Having established the feasibility of helicopter delivery of dry hygroscopic seeding agents, the next logical step was the field testing of the helicopter fog dispersal equipment and treatment procedures in actual fog. Thus the 30-day field test in West Virginia was designed so as to simulate the tactical situations whereby fog dispersal support would be provided by helicopters positioned at a staging base equipped with the necessary fuel reserves, seeding materials, and ground support facilities. A unique feature introduced in this phase was the helicopter borne Air Rescue Hovering Set/ Electronic Location Finder (ELF), AN/ARD-21.

(c). March-April, 1972, Nantucket Airport and Otis Air Force Base, Mass., (Cape Cod).

This final test of the series was designed to apply the warm fog dispersal technique on low stratus and advective type fog in the Cape Cod area. Emphasis was placed on the use of Marine Corps personnel in all phases of ground support and airborne operations.

(d). Previous Reports.

The detailed results of the Quantico/Elmira and the Lewisburg tests were presented in separate reports. This report presents the results of the Cape Cod tests as well as a summary of the two previous tests.

b. Background

(1) Considerable progress has been made in the past five years relative to the understanding of warm fog (temperature above 0°C) characteristics and how they can be modified. This has come about largely by the application of computer models to study the fog and to aid in the determination of seeding agent particle size and concentration that will be most effective in the fog modification process. Jiusto (1967), Silverman (1970), and Koenig (1971), in extensive evaluations of the hygroscopic method of warm fog dispersal, showed that the improvement in visibility caused by the seeding is dependent on the size and quantity of hygroscopic material used. The effects of particle size and seeding concentration were further demonstrated in fog chamber experiments by scientists at Cornell Aeronautical Laboratories under contract to the National Aeronautics and Space Administration (NASA). The results of these scientific experiments of hygroscopic particle seeding confirmed earlier hypotheses relative to the dispersal of warm fog.

(2) Significant success has also been made during the past few years in clearing certain types of fog by helicopter downwash mixing. The "Lewisburg Program" conducted by the U. S. Air Force, Army and Marine Corps, demonstrated this

technique and its applicability to certain fog conditions in which the fog depths are 300 feet or less. The report on this project by Plank et al (1970), is an excellent summary of the theoretical basis, its limitations, and recommended procedures for application of the technique. Results of field experiments related to the two techniques cited above gave strong evidence that a combination of the downwash and hygroscopic seeding methods would clear fog and stratus much more effectively than when used separately.

(3) Two major factors which have previously delayed the operational employment of hygroscopic seeding techniques were; the lack of suitable hygroscopic materials dispensers and ground support equipment, and the lack of a practical method of accurately positioning the seeder aircraft over fog covered ground targets. Progress toward solving these problems has been made in the Marine Corps sponsored projects; the results of which are summarized in the concluding section of this report.

2. DISCUSSION

a. General Description of Helicopter Downwash Seeding Equipment

(1) Seeder Helicopters. The seeder vehicle used in this series of tests was the CH-46. This is a medium sized twin-rotor helicopter with a takeoff gross weight of approximately 23,000 pounds. External as well as internal dispensing pods can be carried as shown in Figure 1.

(2) Target Finder Helicopter. The AN/ARD-21 hovering set, consisting of an antenna array, two receivers, and a control unit are carried aboard the target finding helicopter to locate the ground target from above the fog. This electronic location finder (ELF) provides steering information that enables the helicopter pilot to locate and hover directly over any UHF radio. Figures 2 and 3 show views of a CH-46 helicopter with the ELF installation. The portable ground radio used in these tests is shown in Figure 4.

(3) Helicopter Seeding Pods. Pressurized rubber containers of the type shown in Figures 5 and 6 were used to dispense the seeding agent. The containers, fully loaded, carry approximately 2000 pounds of dry materials. When pressurized to 5 psi, the seeding materials can be released at rates varying from 50 to 500 pounds per minute. Normally, two filled seeding pods were retained on the staging base helicopter pads, ready for use as fog occurred at the target site.

(4) Urea Fog Dispersant. Powdered urea, milled and blended by Sierra Research Corporation, was

Figure 1. A CH-46 helicopter transporting an external and an internal seeding pod. Each of the 66 cubic foot pods could carry 2000 pounds of the blended urea seeding agent.

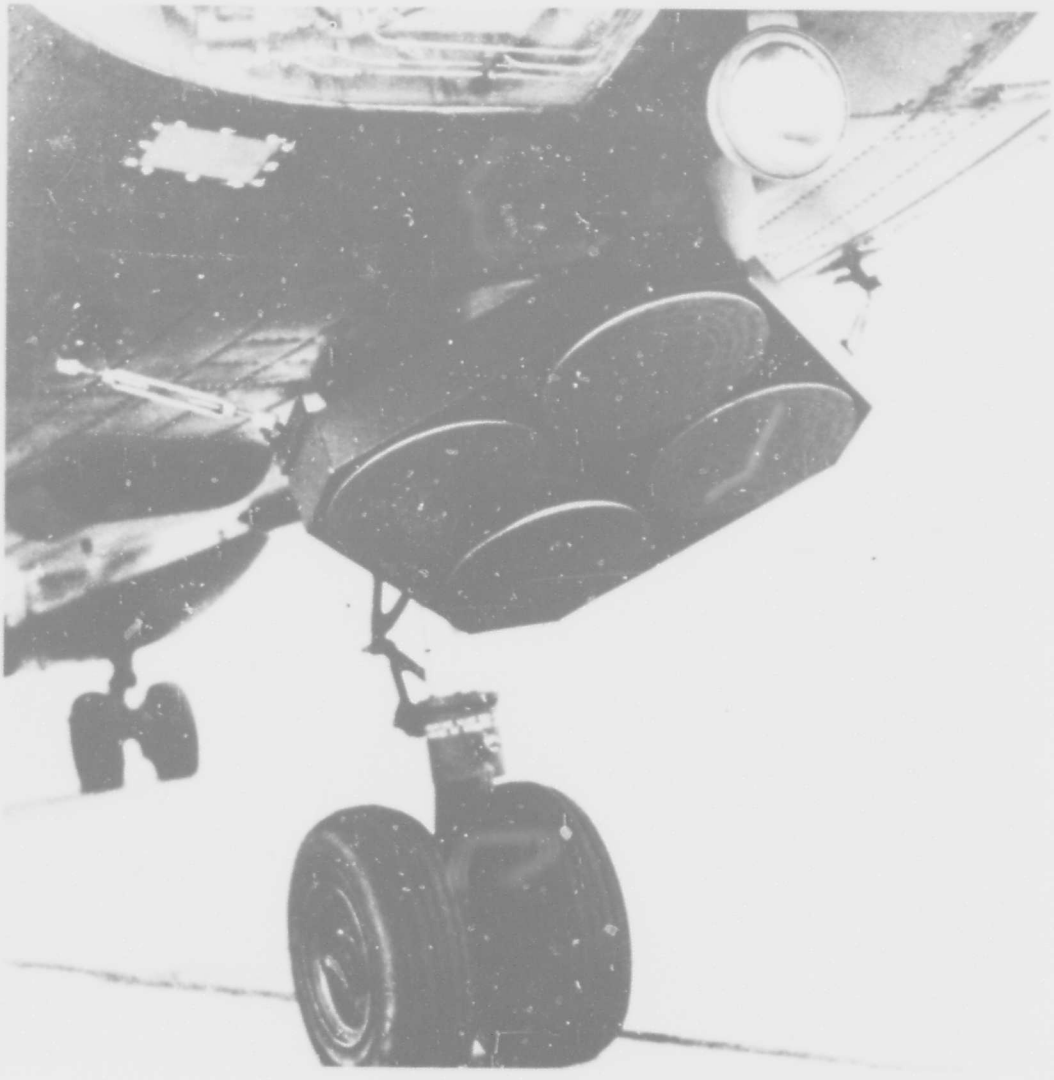


Figure 2. CH-46 target helicopter showing the ELF exterior antenna.

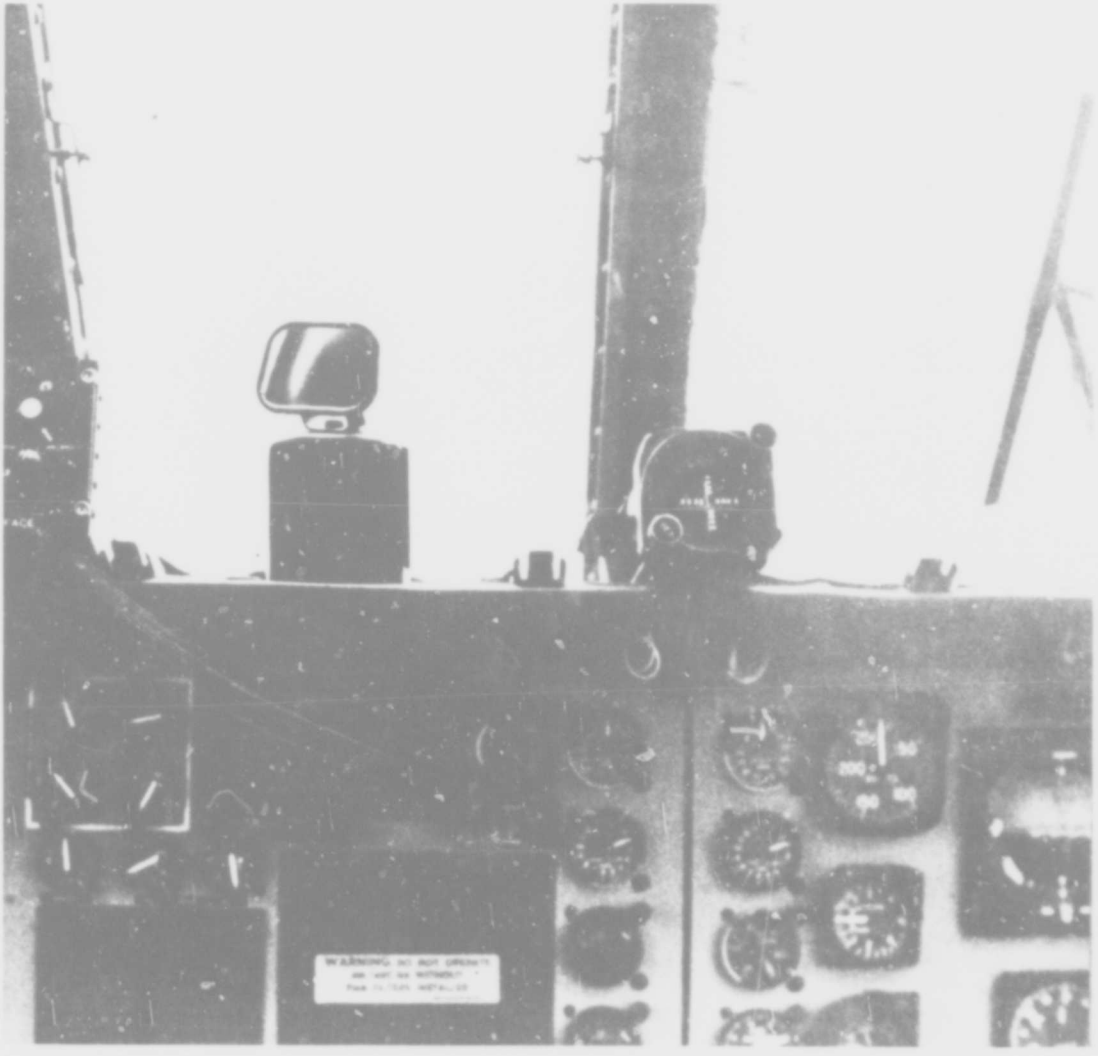


Figure 3. The ELF flight indicator as installed above the instrument panel of the CH-46.

Figure 4. The upper photograph shows the portable UHF radio used to provide the target signal for the airborne Electronic Location Finder (ELF). The lower photograph shows the battery powered TACAN that was also positioned at the fog target in Lewisburg.

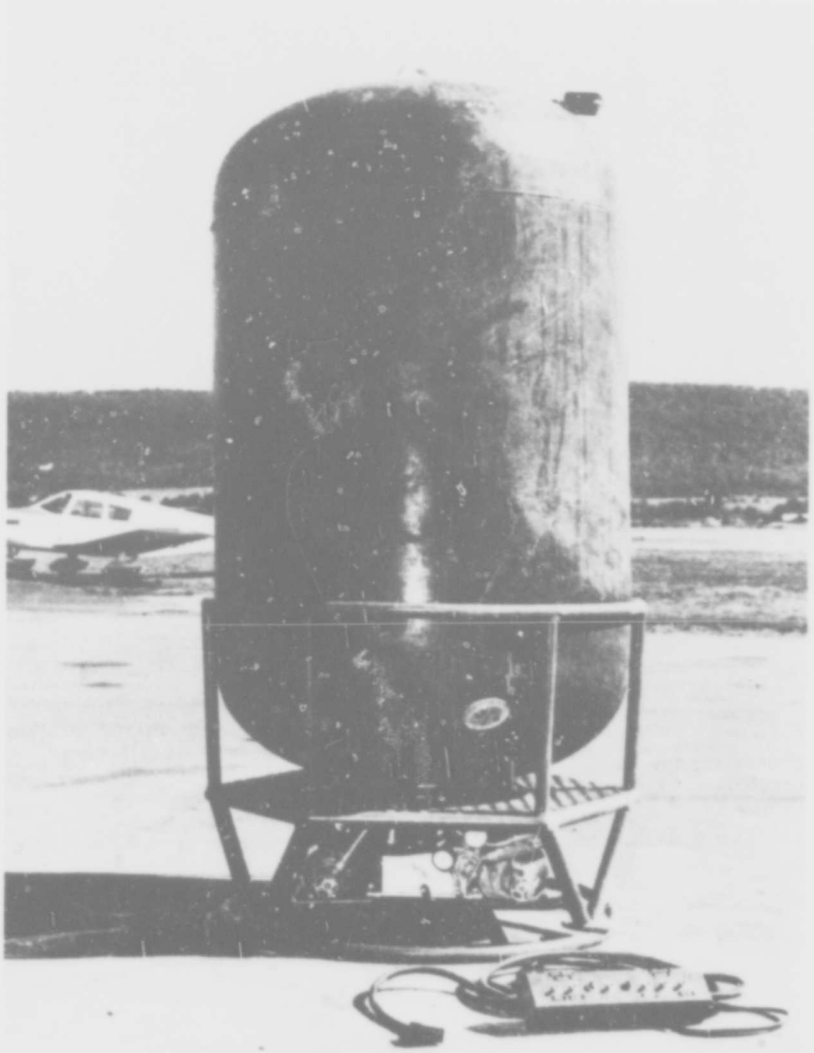


Figure 5. Close-up view of the pressurized rubber seeding pod, used to dispense seeding material from a suspended position beneath the CH-46 helicopter. The aeration and flow control valves are electrically activated through the control panel that is carried in the helicopter.

Figure 6. CH-46 carrying an external seeding pod. In the hover mode shown above the seeding plume can be seen as it spreads into the full rotor wake 75 fee below the rotor blades.

Figure 7. View of a CH-46 dispensing seeding material from an internal pod at a flow rate of 400 pounds per minute. The off center release points, directly beneath the rotor blades provide a rapid and uniform distribution of seeding material throughout the rctor wake.

specified as the primary hygroscopic seeding agent in these tests. While the material was not rigidly classified with respect to particle size (approximately 90% below 75 micron diameter), it is accepted as a practical, commercial-grade, warm fog dispersant. The formulation of blended urea was varied slightly to determine the amount of free-flowing agent that is most appropriate for field use. It was found that a 2% by weight blend of fumed silica (trade name Cabosil) gave good results as long as proper protective measures were taken during the handling process. When increased amounts of Cabosil were tested there was a further improvement in flow properties, but these blends were not used regularly because of the insoluable residue that might accumulate on equipment in the fallout area.

(5) Microencapsulated Urea. During the last test of the series, provisions were made to use an advanced form of microencapsulated urea manufactured by the National Cash Register Company. Although much more costly than the blended urea, the microencapsulation process produced a relatively uniform particle size distribution, 15-50 micron diameter, and improved handling properties. Test circumstances prevented acquisition of data relative to the fog clearing capabilities of the microencapsulated urea.

(6) Materials Handling Equipment. The basic items of equipment employed at the staging base consisted of a fork lift and a 90 cubic foot auger wagon used to transfer the dispersant into the seeding pods as shown in Figure 8.

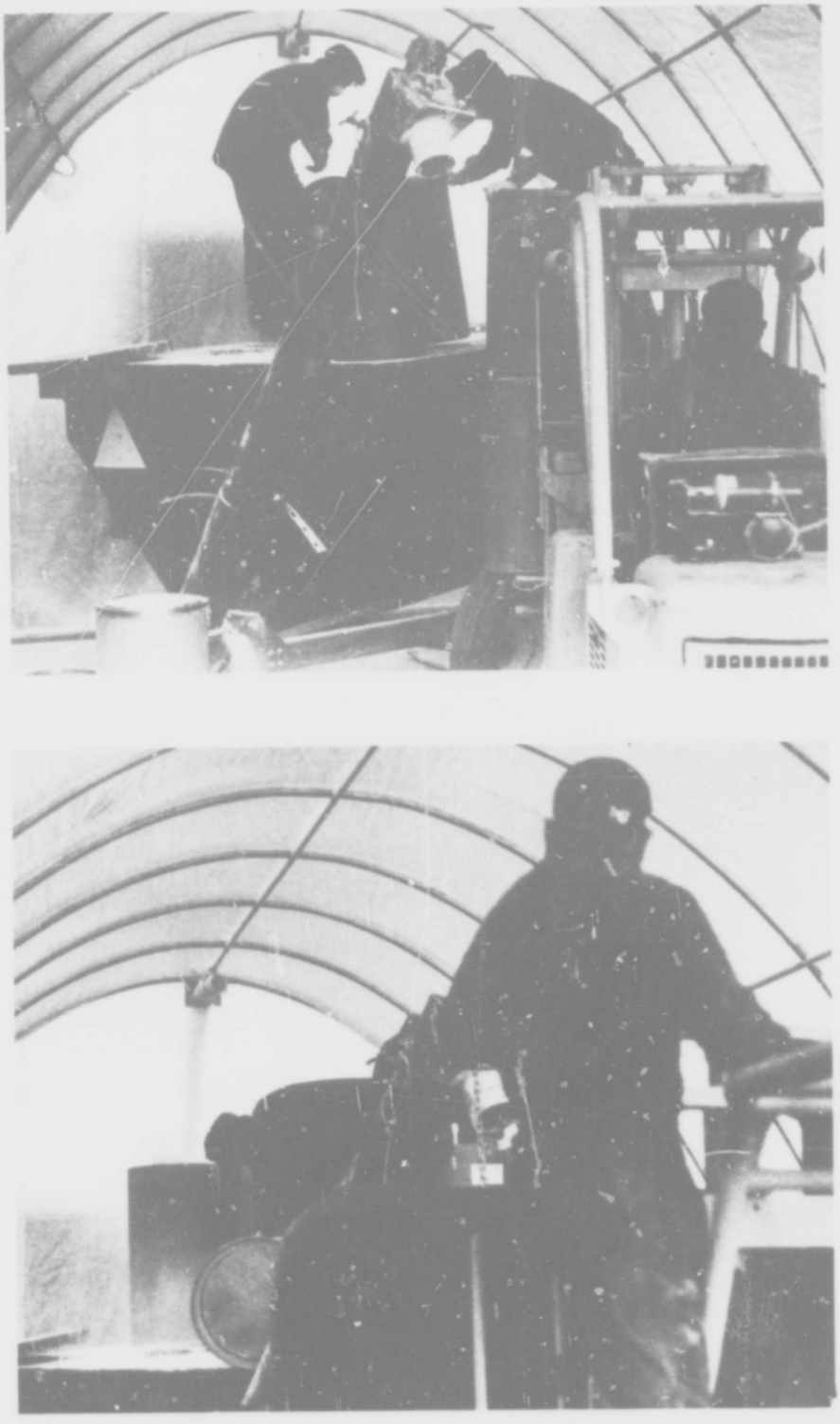
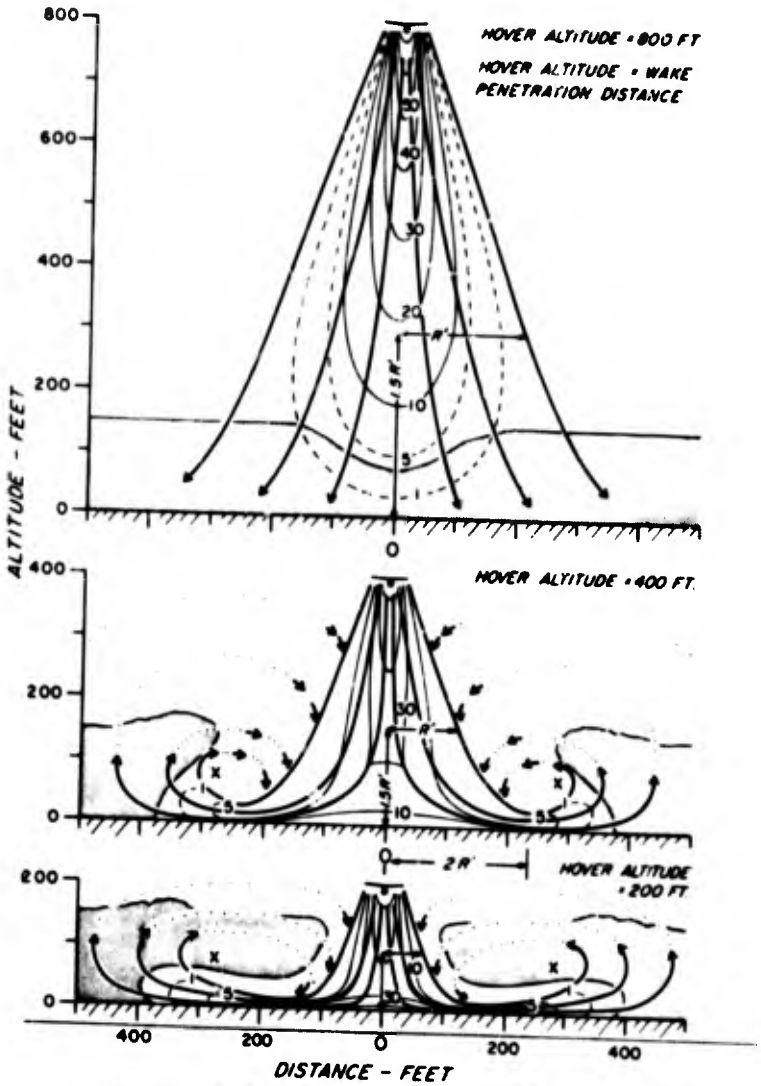


Figure 8. Auger wagon used to transfer seeding materials into the helicopter pods. The portable shelter shown was equipped with a dehumidifyer so as to protect the hygroscopic powder from moisture contamination.

(7) Materials Handling Shelter. During the early phases of the field tests, high humidity and frequent rains caused moisture contamination of the hygroscopic seeding materials as they were being handled on site. These conditions as well as the problem of dust contamination were overcome by installation of a 15 foot by 30 foot moisture and dust proof enclosure. This portable structure (see Figure 8) was equipped with a 150 cubic foot per minute dehumidifier, capable of maintaining the relative humidity at approximately 30%.

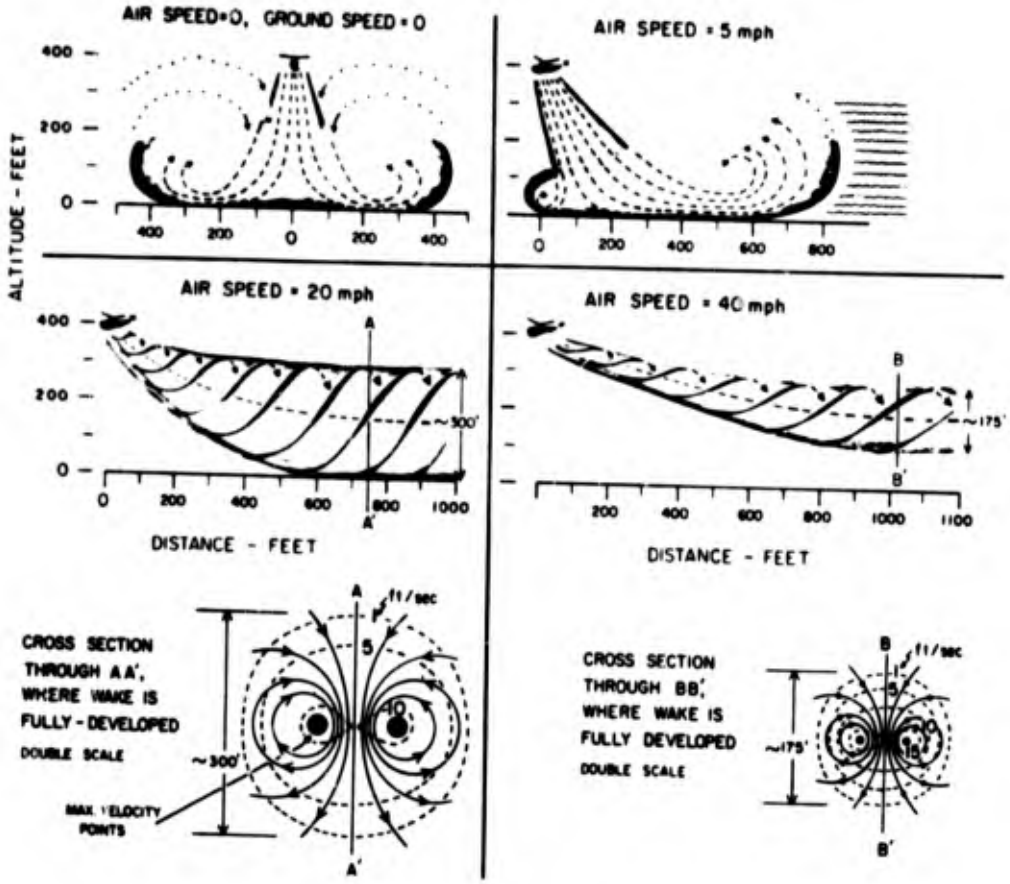
b. Treatment Procedures

(1) Downwash Clearing. The theoretical and practical aspects of helicopter downwash clearing have been thoroughly studied and demonstrated in conjunction with other military and civil projects. The joint U. S. Army-U. S. Air Force report, Plank, et al (1970), was used as the basic reference with respect to downwash clearing techniques, helicopter wake dimensions, and volumetric computations. During the above cited project, operationally significant clearings were, in general, attainable without seeding agents in fog layers up to 300 feet thick. Downwash clearing patterns and downwash clearing techniques used in this series of Marine Corps tests were similar to those cited in the above reference. Figures 9 and 10 illustrate the approximate circulation and dimensions of helicopter wakes at different airspeeds and altitudes.



The Circulation Structure and Associated Fog-Clearing Effects of Helicopter Wakes in the Hover State at Different Flight Altitudes. The upper diagram illustrates a situation wherein the wake penetration distance of a helicopter hovering 800 ft above the ground is precisely equal to the hover altitude. The streamlines (solid) and isotachs of downwash velocity (dashed, in ft/sec) are shown. Fog clearing in such situations will be ineffective and will merely "dish in" the fog top. The second diagram illustrates how, at a lower hover altitude of 400 ft, where the downwash jet is "impinged" on the surface boundary, the wake air will spread radially across the ground surface and will eventually rise in the regions beyond the circulation centers of the spherical-type vortex. The associated, to be anticipated, fog-clearing situation is also indicated. The bottom diagram reveals how the wake air, at the yet smaller hover altitude of 200 ft, spreads farther across the ground at larger velocity, than at the 400 ft titude.

Figure 9. The circulation structure of helicopter wakes at different flight altitudes, Plank, et al (1970).



Diagrams are shown indicating the schematic nature of the wake circulations of a medium-sized helicopter flying at 400 ft altitude above the ground and at 0, 5, 20 and 40 mph airspeeds. The circulation at zero airspeed, in the hover state, resembles that of an inverted, spherical vortex. With airspeeds exceeding zero but smaller than that of transitional lift (which occurs at about 15 mph, refer to text definition and discussion), the circulation is like that of a "skewed" spherical vortex which is elongated in the flight path direction. For speeds exceeding the transitional lift speed, such as the illustrated 20 and 40 mph speeds, the helicopter wake has the form of a trailing vortex sheet. In the fully-developed state of the wake, indicated by the section lines A A' and B B', the circulations are those of a line-vortex pair of opposed circulation type. The nature of the circulations is shown in the expanded cross-section sketches of the bottom diagrams. The dimensional scale of the wake circulations decreases with airspeed, but the intensity of the circulations increases with airspeed. It should be emphasized that the streamlines shown in the upper diagrams, for the 20- and 40-mph wakes, are schematic only. The streamlines actually lie within sectional planes and there is little or no component of circulation in the flight path direction

Figure 10. Circulation structure of helicopter wakes at different airspeeds, Plant, et al (1970).

(2) Seeding Patterns. During the orientation phase of the field test, two fog seeding methods were applied. Initially, seeding of the hover downwash was tested but the excessive speed in which the seeding agent was driven to the surface did not allow sufficient time for the seeding agent to modify the fog. Primary emphasis was then diverted to fog top seeding. Ideally, the fog dispersant should be distributed evenly above the fog layer at an appropriate upwind distance so that fog modification processes will be completed upon arrival of the seeded fog at the target. Figures 11 and 12 illustrate how the helicopter, with its rotor-mixing and maneuvering capability can be effectively employed in the fog modification process.

(3) Targeting. One of the most critical aspects of hygroscopic seeding by airborne methods is the positioning of the seeded fog and resultant clearings over the intended target. Numerous factors such as the drift, thickness and physical character of the fog affect the modification process. All of these factors, as well as the matter of materials distribution, must be taken into account in targeting computations. In these test seeding material release was made at 100 feet above fog top. Figure 13 is a nomogram used to make the first approximation of offset distance.

(4) Seeding Concentrations. Estimates of seeding requirements were made using nomograms similar to those shown in Figure 14. While not based on precise mathematical computations, these nomograms do give consideration to theoretical results obtained by mathematical models and are suitable for field use.

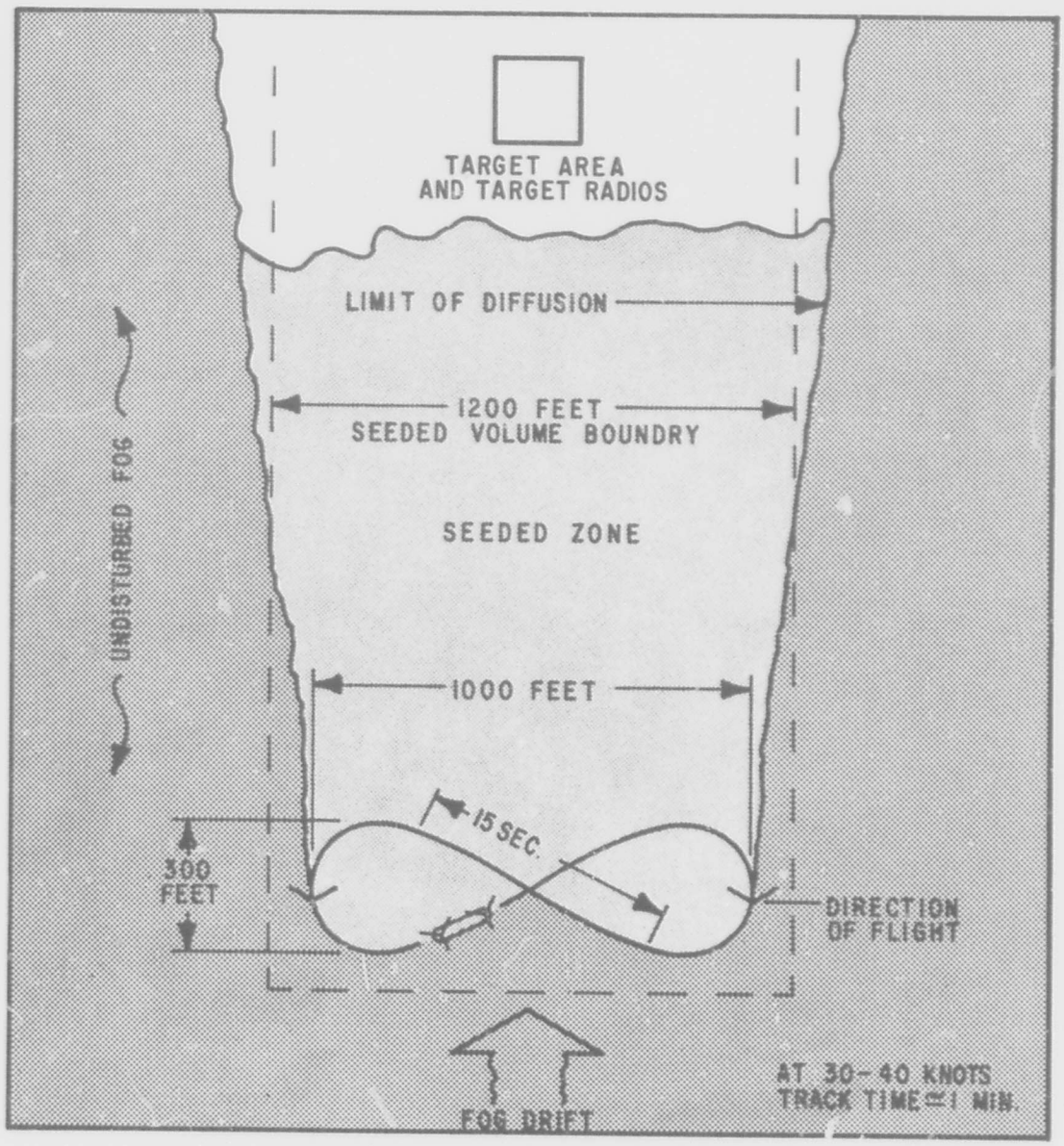


Figure 11. Typical track for release of seeding material 100 feet above fog top. For nominal fog drift (3-5 knots) the 1 minute pattern should be flown over the same track with respect to the ground. In this way the seeding plume should diffuse evenly into the fog that drifts though the seeding track.

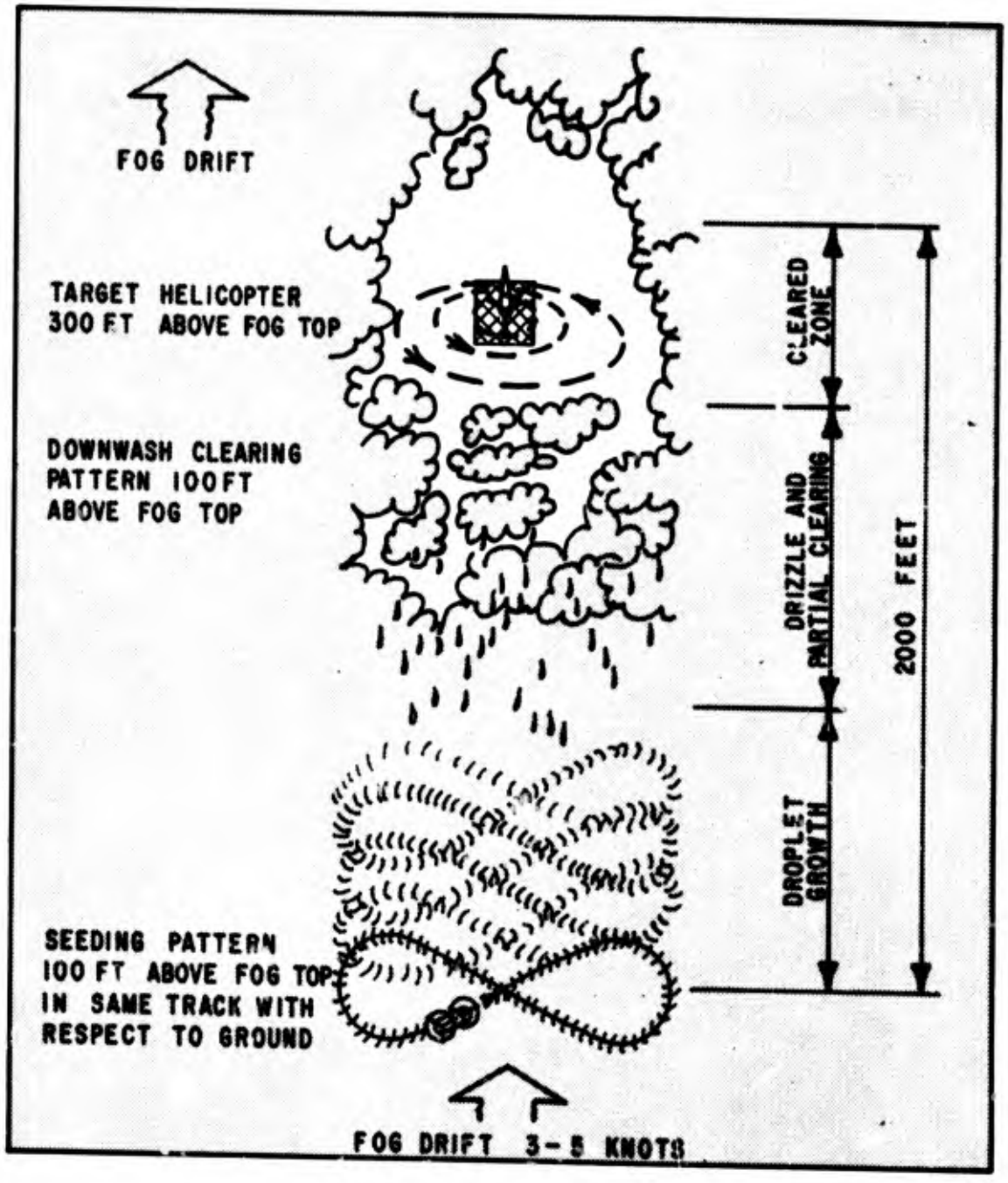


Figure 12. Schematic of a fog clearing operation. In the 3-5 knot drift situation shown, the seeding pattern is flown over the same track with respect to the ground, assuming that the seeding material flow rate is adjusted according to the fog depth. See Figure 14 (Flow Rate)

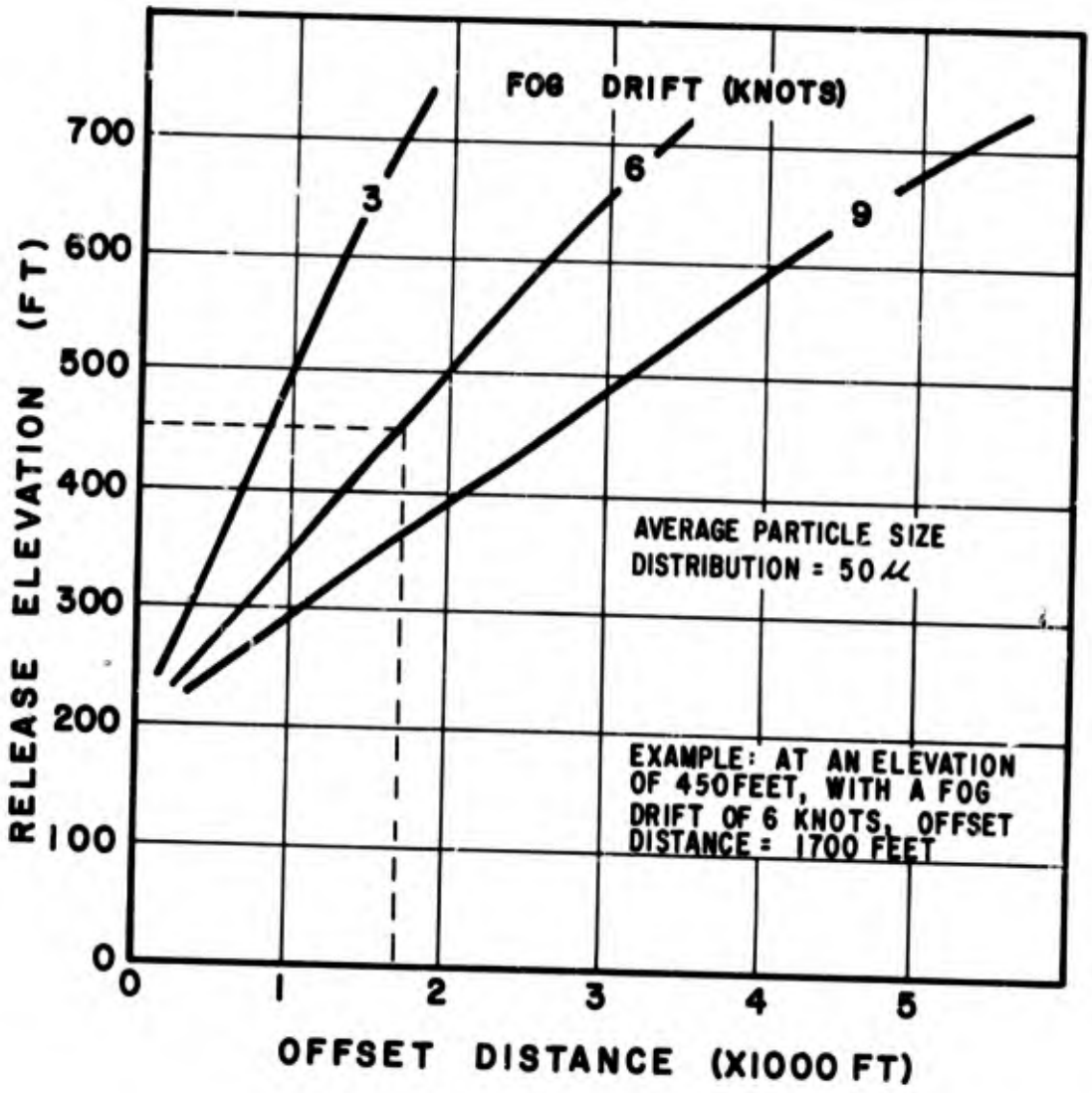


Figure 13. Nomogram for estimating offset distances when seeding drifting fog. Changes in fall rates due to droplet growth and downward transport caused by the helicopter wake are taken into account.

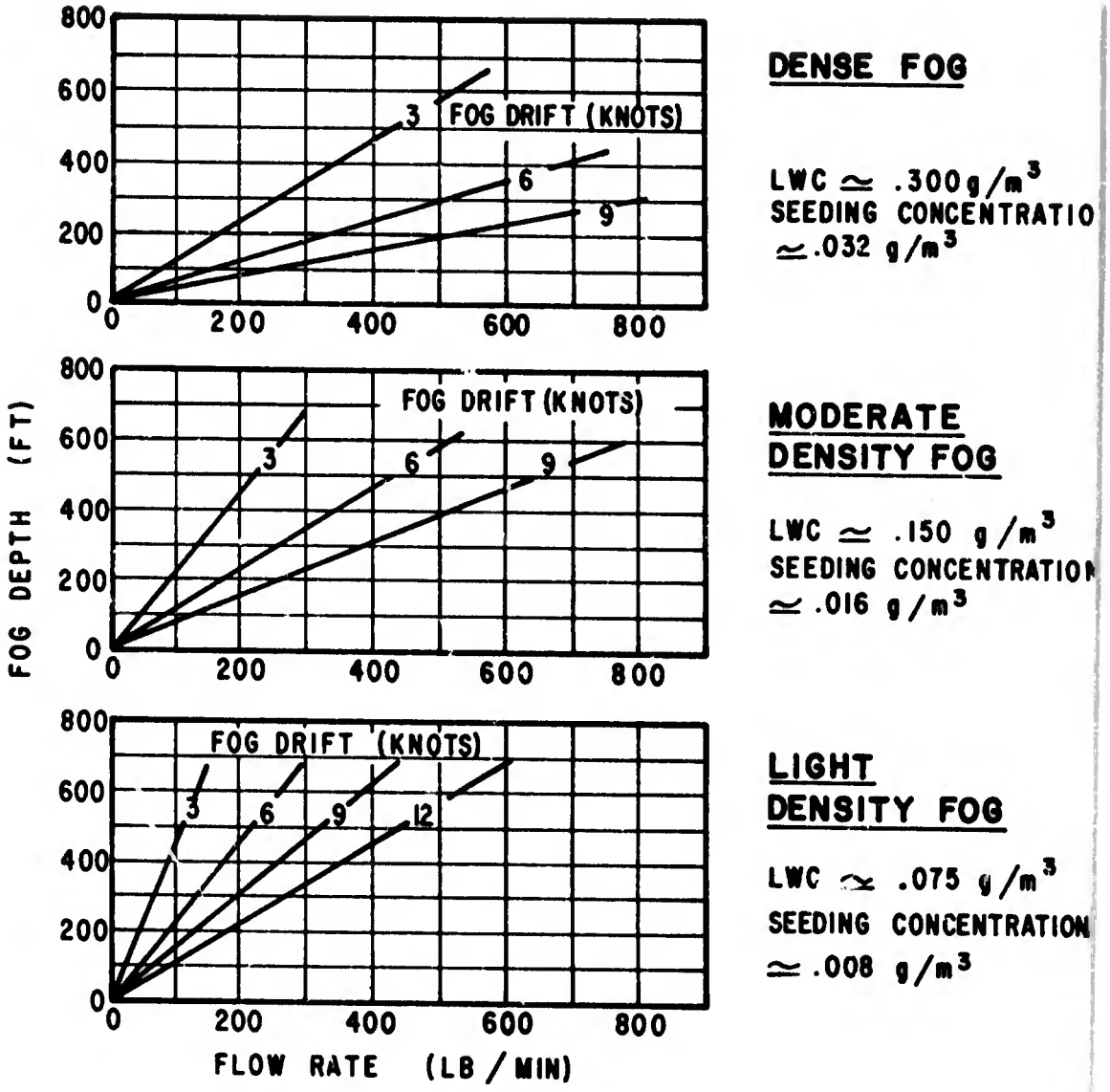


Figure 14. The above nomograms may be used to determine first order approximations of flow rates when flying the seeding pattern shown in Figure 11. Suggested flow rates are shown for treatment of dense advection fog, moderately dense fog, and light radiation fog. The flow rates corresponding to the fog depths and fog drifts shown suggest seeding concentrations from .008 to .032 g/m^3.

(5) Clearing Technique (Seeded Fog). The hygroscopic-downwash mixing technique illustrated in Figure 11 involves several distinct steps. In chronological order they are:

(a). Targeting helicopter hovers over the UHF radio serving as target locator and flight reference point for seeder helicopter.

(b). After verification of fog drift and depth, the seeder helicopter begins a figure eight seeding pattern at the appropriate offset distance upwind of the target helicopter. See offset distance nomogram, Figure 12.

(c). Seeded fog drifts toward target as unseeded fog enters the seeding pattern.

(d). Downwash clearing pattern is initiated by the target finding helicopter when seeded fog approaches the target area. As a cleared area is attained, the target helicopter and/or other helicopters can land through the induced clearing.

c. Summary of Quantico and Elmira Tests

(1) A four week field test was conducted at Quantico, Va., and Elmira, N. Y., 14 August through 5 September, 1970, for the initial calibration and demonstration of the hygroscopic seeding equipment. Only one fog episode occurred during the test period. However, valuable equipment performance data and experience were obtained. Annex A is a summary of the test missions flown at Quantico and Elmira. The detailed results of the test are discussed in an earlier report.

d. Summary of Lewisburg, West Virginia Tests

(1) Warm fog dispersal techniques using downwash mixing and hygroscopic seeding were successfully tested on radiation type fogs at Lewisburg and White Sulphur Springs, West Virginia, 26 July through 29 August 1971. The clearing capability of two medium weight helicopters (CH-46 and H-3) were observed on 13 fog days. Annex B is a summary tabulation of the 40 specific tests conducted on the 13 fog days. When interpreting the time and dimension values entered in the seeding and clearing columns, consideration should be given to the fact that they were derived from airborne and ground observer estimates which varied somewhat depending on their location relative to the particular event.

(2) The results of the Lewisburg tests showed that the effectiveness of fog dispersal by helicopter downwash is considerably enhanced when the fog layer is treated with a hygroscopic seeding agent (unsized urea in this particular test). Some quantative comparisons were made, but the most confident assessment came from helicopter pilots who unanimously described the seeded fogs as being "much easier to work" than the unseeded fogs. A detailed discussion of the Lewisburg field test is contained in an earlier report.

e. Cape Cod Tests

(1) Purpose. A third field test of warm fog dispersal techniques using helicopters was conducted in the Cape Cod area of Massachusetts, 27 March to 21 April 1972. The purpose of the test was to develop further

the Marine Corps' capabilities to conduct warm fog dispersal operations using the combined effects of helicopter downwash and hygroscopic seeding. Two additional objectives were included in the Cape Cod tests:

(a). To evaluate the effectiveness of the fog modification technique in warm advection fog and low stratus.

(b). To familiarize Marine Corps aircrews and ground support personnel with hygroscopic materials handling and application techniques.

(2) Operational Sites. The Cape Cod tests were designed to disperse warm fog or low stratus over the runways of Nantucket Airport, Massachusetts, using CH-46 helicopters staging out of Otis Air Force Base. The Otis AFB runways were used as an alternate fog dispersal site when conditions were not suitable for operating at Nantucket.

(3) Equipment and Materials

(a). Helicopters and Pods. Two CH-46 helicopters were used in the fog dispersal operations. The seeder CH-46 was equipped to carry a self-contained seeding pod, either suspended below the helicopter or as an internal load. The pods weigh approximately 300 pounds and can carry approximately 2000 pounds of urea fog dispersant. The pressurized pods are moisture proof and can be pre-loaded and used as open storage containers.

(b). Target Finding Equipment. One of the CH-46 helicopters was equipped with an AN/ARD-21 Air Rescue Hovering Set (ELF). The ELF equipment on board the

aircraft, and the portable UHF radio at the ground target provide steering information that enables the pilot to precisely locate the target while flying above the fog.

(c). Hygroscopic Seeding Material. Two types of seeding material were available for use in these tests; blended urea manufactured by Sierra Research Corporation, and microencapsulated urea manufactured by National Cash Register Company. While the blended urea is "unsized", the average particle size is about 25 micron diameter, with 90% of the particles being under 75 micron diameter. The micro-encapsulated urea is a carefully sized product in the range of 15-50 micron diameter.

(d). Ground Instruments. The conventional airport weather observations were supplemented by an instrument vehicle which provided a portable liquid water content sensor, a wind instrument and cameras at the target location.

(e). Sampling Aircraft. Airborne sampling and observations were made with a Cessna 401 aircraft. The following parameters were recorded automatically on board the aircraft:

(1) Temperature
(2) Dew point
(3) Relative humidity
(4) Liquid water
(5) Vertical velocity
(6) Altitude

(7) Airspeed

(8) Position data

(9) Time

(10) Drop Size

(f). Photographic Equipment. Photographic documentation was provided by 35 mm hand cameras and 16 mm motion picture cameras positioned at the ground site, the target helicopter and the Cessna 401 sampling aircraft.

(g). Materials Handling Facilities. Several specialized ground support items were provided in order to protect the hygroscopic materials from moisture and to expedite the pod filling functions. The principal items provided on site were: a 15 ft x 30 ft portable shelter equipped with a dehumidifier; a gasoline powered auger wagon for transfer of materials into the pods; and a conventional fork lift for maneuvering the pods.

(4) Manpower Requirements

(a). Marine Corps Operations Personnel. Military personnel who participated in the Cape Cod Field Test were drawn from Marine Helicopter Squadron One (HMX-1) and the Marine Corps Development Center. One pilot and one NCO had participated in a previous fog dispersal field test. The categories of personnel employed in this test are listed below. This team configuration can be considered typical of that required for ground and airborne support of an operational unit.

The photography, data collection, aircraft maintenance and project supervisory personnel are not included in the listing below:

(2) pilots and (1) crew-chief per helicopter
(1) "dump master" per seeding helicopter
(1) NCO to supervise ground support relative to transfer of materials into seeding pods, operation of materials handling equipment, and dispenser pod maintenance.
(2) equipment technicians to operate ground support equipment and perform materials handling functions.

(5) Treatment Procedures. The seeding patterns and clearing techniques employed in this test were as discussed in paragraph 2b. A more detailed description of seeding procedures, clearing patterns, equipment maintenance are contained in a "Handbook of Instructions for Warm Fog Dispersal Using Helicopter Downwash and Hygroscopic Seeding".

(6) Fog Occurrences. The actual frequency of fog and low stratus was considerably below the Cape Cod climatological average for April. During the 4 week test period the ceiling-visibility was below 300 feet and 1 mile (daylight hours) on only 4 days at the Nantucket test site. All of these fog occurrences were of less than one hour duration. Accordingly, none was suitable for evaluation purposes. One low stratus episode at Otis AFB, the alternate test site, was of sufficient duration to allow treatment and proper evaluation. This occurred on 12 April when

the prevailing surface weather, 05:30 to 7:00 hours local standard time was; 300 feet ceiling, 7/8 mile visibility in fog, wind northeast 5 knots, and temperature 33 degrees.

(7) Summary of Operations. A total of 12 test flights were conducted during the period. For details, see the summary tabulation in Annex C. As pointed out in paragraph 2e (6) above, there were no fog occurrences suitable for evaluation at Nantucket. The single actual dispersal operation flown was at Otis AFB, the alternate test site on 12 April 1972. The results of this very successful test are presented as a case study in Annex D.

3. CONCLUSIONS

a. General Assessment of Downwash Seeding

The techniques applied in these tests were successful in dispersing warm fog to the extent that helicopters were able to descend safely through clearings created in fog layers up to 700 feet thick. This Marine Corps test, like earlier laboratory and field experiments, demonstrated that the cloud physics aspects of hygroscopic seeding are sufficiently developed to produce meaningful modification of warm fog. Equipment designs and materials handling techniques were proven reliable for field use. One of the major continuing problems in airborne seeding operations is targeting, i.e., placement of the seeding materials in the proper upwind location, so that the modified fog will drift over the intended ground target. Fog drift, turbulence, and shear are some atmospheric variables which complicate the targeting process. This series of tests demonstrated that medium weight helicopter, because of their maneuverability, rotor mixing action, and slow flight capability, can minimize the deterrent effects of these variables.

b. Target Finding Equipment

The AN/ARD-21 (ELF) hovering set was an essential feature of the helicopter fog dispersal system. The success of these tests was greatly dependent upon the ability to precisely locate the ground target while hovering above the fog tops. The ELF, using a portable radio at the ground site, consistently positioned the target helicopter over the fog target. Such a target location device

would also be essential in tactical conditions.

c. Seeding Pods

The pressurized seeding pods, designed by Sierra Research Corporation and successfully demonstrated in the series of three field tests, have proven to be a suitable container for storage and dispensing hygroscopic fog dispersants from helicopters. Both the internal and external type pods were found appropriate for Marine Corps use. The external pods provide the feature of instant pick-up of loaded pods without degradation of internal cargo capacity of fuel loads. On the other hand, internally loaded pods proved more convenient for long range flight and, due to the off-center delivery of seeding material close to the rotor blades, the seeding particles are distributed more rapidly and uniformly throughout the helicopter downwash.

d. Clearing Capability

(1) When hygroscopic seeding was used alone in these tests (single application at moderate concentration) the degree of visibility improvement was insufficient to permit safe visual descent of helicopters. On the other hand, hygroscopic seeding was found to be very useful in combination with downwash clearing techniques.

(2) While quantitative data is limited, photography and helicopter observations clearly show that the effectiveness of fog modification using helicopter downwash is considerably enhanced by proper application of a hygroscopic seeding agent (unsized urea in these particular tests). First order estimates indicate that the size and persistence of clearings produced during the seeding operations

are more than double those made in similar fogs using downwash only.

e. Crew Indoctrination

Results of the final field test, (Cape Cod April 1972) indicate that one week is a reasonable period of time to allocate for the purpose of Marine Corps ground and flight crew indoctrination. An instruction manual "Warm Fog Dispersal by Use of Helicopter Downwash and Hygroscopic Seeding" has been compiled for use as a guide in such indoctrination programs.

f. Materials Handling

(1) To avoid moisture and dust contamination in the field, emphasis must be placed on proper handling of hygroscopic material. In general, blended urea should not be exposed to ambient relative humidities of more than 50%. Since such dry conditions, including storage, may not prevail at operating locations, closed handling systems, including a de-humidified shelter, are mandatory. Alternatively, pre-filling of the pods at a factory or depot under controlled environmental conditions will preclude contamination of the material, and minimize manpower and equipment requirements in the field.

(2) Microencapsulated urea, with its ethel cellulose coating, is less vulnerable to moisture in handling and storage. The manufacturer states that the material remains stable at 90% relative humidity.

REFERENCES

Jiusto, J. E., 1967: "Nucleation Factors in the Development of Clouds," Ph.D. Dissertation in the Department of Meteorology, Pennsylvania State University.

Kocmond, W. C. and J. E. Jiusto, 1968: "Investigation of Warm Fog Properties and Fog Modification Concepts", NASA Contractor Report CR-1071, Cornell Aeronautical Laboratory, Inc., June, 1968.

Koenig, L. R., 1971: "Numerical Experiments Pertaining to Warm Fog Clearing." Monthly Weather Review, Vol. 99, No. 3, National Oceanic and Atmospheric Administration, March, 1971.

Plank, V. G., A. A. Spatola, J. R. Hicks, 1970: "Fog Modification by Use of Helicopter," Joint Army-Air Force publication; Research and Development Technical Report ECOM-5339, and Air Force Cambridge Research Laboratories Environmental Research Paper No. 335, December, 1970.

Silverman, B. A., and B. A. Kunkel, 1970: "A Numerical Model of Warm Fog Dissipation by Hygroscopic Particle Seeding." Journal of Applied Meteorology, Vol. 9, pp. 726-633.

ANNEX A.

Summary of Flights Conducted at Quantico and Elmira

Test No.	Date/ Time	Dispen. Unit	Seeding Material	Delivery Pattern and Duration	Pres/Rate of Flow	SFC VSBY	SFC Wind	REMARKS
1	8/18/70 1330 EDT	FDP-1	None	N/A	N/A	No Fog		No release due to power inverter inoperative. Aerodynamic checks satisfactory at airspeeds 0 to 100 kts.
2	8/19/70 1330 EDT	FDP-1	None	N/A	N/A	No Fog		No release due to failure of dump valve actuator - microswitch failure
3	8/20/70 1400 EDT	FDP-1	M-200	Straight line 600' alt. 20-30 kts 3 min release	10→5 psi Full Open 500#/min	No Fog		Plume heavy & steady first 2-1/2 min. At 3 minutes pressure fell off to 0; flow stopped. Repressurized to obtain erratic flow as pod emptied.
4	8/21/70 1400 EDT	FDP-1	M-200	Straight line 600' alt. 20-30 kts 3 min release	10→3 psi Full Open 400#/min	No Fog		Plume steady 100' wide at 300' distance from rotor, widening to 500' in vortex beyond 800'.
5	8/21/70 1500 EDT	FDP-2	Empty	Straight flight and turns 0-100 kts	N/A	No Fog		Flight characteristics good while inflated. When collapsed, severe swaying occurred at 75 kts and above.

Test No.	Date/ Time	Dispen. Unit	Seeding Material	Delivery Pattern and Duration	Pres/Rate of Flow	SFC VSBY	SFC Wind	REMARKS
6	8/25/70 0830 EDT	FDP-1	M-200	Circular-1000 yds diam Alt 500', 10-30 kts, 4 short bursts 30, 30, 60, 120 sec.	5 psi Full Open 400#/min	2 Mi light ground fog	190°/03	Plume 3-500' wide at distance of 800'. Hover at 500' alt gave plume deflection at ground having 1000' in diameter.
7	8/26/70 0720 EDT	None	None	Circular, just above fog layer at 350' abv grnd 10-20 kts	N/A	1/8 mi fog 350' thick	Calm	Clearing in sloping downwash vortex about 50 ft in diameter disappeared in less than 1 min. Ground observers felt effects of downwash.
8	8/26/70 0750 EDT	FDP-1	Deepwater Urea	1000 yd decreasing spiral, 400' alt, 20-30 kts at fog top-45 sec.	6-8 psi Full Open 400#/min	less than 1/8 mi fog, 350'-400' thick	Calm	Circular clearing appeared in treated area. Hanger and aircraft visible on ground. Clearing remained for about 5 min before closing.
9	8/27/70 0800 EDT	MRI	Deepwater Urea	Hover turns 200' 3 min Release	N/A	1-1/2 mi F	Calm	Flow erratic. Touchdown released part of bridged material. Flight terminated due to power cable disconnect.
10	8/27/70 0845 EDT	FDP-1	Deepwater Urea	Hover turns 200' 3 Min Release	5→0 psi Full Open	5 Mi	250°/05	Flow too erratic to calibrate. Touchdown caused flow to resume. Flow continued erratic as pressure dropped to 0 psi. Small lumps fell out of plume.

Test No.	Date/ Time	Dispen. Unit	Seeding Material	Delivery Pattern and Duration	Press/Rate of Flow	SFC VSBY	SFC Wind	REMARKS
11	8/28/70 0830 EDT	FDP-1	M-200	Decreasing spiral 600' 10-25 kts 3 min Release	5→2 psi Full Open 300#/min Average	No Fog	Calm	Flow steady on first 3 min release, then erratic due to urea remaining in pod from previous day.
12	8/31/70 0800 EDT	FDP-2	M-200	Decreasing spiral 400' 10-25 kts 1 min Release	5 psi Full Open 400#/min	No Fog	330°/08	Excellent plume 300' wide at distance 500' behind rotor. As downwash deflected, ground coverage was in excess of 500' wide.
13	8/31/70 0900 EDT	FDP-1	Deepwater Urea	"	5→0 psi Full Open Flow Erratic	No Fog	340°/10	Flow erratic. No calibration.
14	9/1/70 0800 EDT	FDP-1	Deepwater Urea	"	5→0 psi Full Open Flow Erratic	No Fog	220°/12	Flow erratic with small lumps falling out of plume.
15	1/9/70 0900 EDT	FDP-2	M-200	"	5 psi Half Open 250#/min Average	No Fog	230°/10	Excellent plume spreading 300' to 500' wide at distance 800' from rotor.

Test No.	Date/ Time	Dispen Unit	Seeding Material	Delivery Pattern and Duration	Pres/Rate of Flow	SFC VSBY	SFC Wind	REMARKS
16	9/2/70 0830 EDT	FDP-1	Deepwater Urea	Decreasing spiral, 600' 10-25 kts 1 min Release	5→0 psi Full Open Erratic	0 mi variable 1 mi patchy stratus 500' thick	250°/05	Lift-off pod pressure-0 psi. Pressurized aloft in 5 min. Equipment problems & airport traffic precluded seeding release on fog. Flow erratic, small lumps.
17	9/2/70 0925 EDT	FDP-2	Deepwater Urea	"	6→0 psi Full Open 300#/min	No Fog	230°/09	Good flow and plume 1st two releases, then flow became erratic with pressure falling off rapidly.
18	9/3/70 0800 EDT	FDP-1	Deepwater Urea	300' Hover accelerating to 60 kts 2 min releases	5→2 psi Full Open 250#/min Average	No Fog	Calm	Excellent flow, plume 50' wide until intercept wake, then about 300' wide. With airspeed above 30 kts plume did not exceed 100'.
19	9/3/70 0845 EDT	FDP-2	"	"	10→7 psi Full Open 400#/min Average	No Fog	130°/05	Excellent flow with hover state plume deflecting at surface to cover area about 500' diameter.
20	9/3/70 0910 EDT	MRI	"	"	N/A	No Fog	Calm	Good flow for 30 sec, then slight surges, becoming very erratic after 1 minute.

Test No.	Date/ Time	Dispen. Unit	Seeding Material	Delivery Pattern and Duration	Pres/Rate of Flow	SFC VSBY	SFC Wind	REMARKS
21	9/4/70 0800 EDT	FDP-1	Deepwater Urea	500' alt hover state accelerating to 60 kts 2 min release	6→4 psi Half Open 200#/min	No Fog	210°/12	Excellent smooth flow. Plume difficult to trace due to strong winds.
22	9/4/70 0915 EDT	FDP-2	"	"	"	No Fog	210°/ 12 gusts20	"

ANNEX B

SUMMARY OF HELICOPTER FOG DISPERSAL TESTS

a. In this annex, detailed information concerning the time of the tests, fog characteristics, seeding amounts, and clearing dimensions are tabulated for each test.

b. The data contained in the tabulation are compiled from ground observers' notes, photographs, and aerial observations. In interpreting the data, it should be recognized that estimates made of the same event by different observers could be considerably different due to variations in location and lighting conditions.

c. Explanatory notes and abbreviations pertaining to the summary tabulation are listed below:

(1). Fog Coverage:

OVC - complete fog coverage

BKN - more than one half coverage

SCTD - one half coverage or less

vrbl - variable with time or in magnitude

(2). Visibility: Estimated (E) values determined by ground observers using visibility markers and landmarks. When no letter prefix is entered, the values are those computed from transmissometer readings.

(3). Fog Drift: Direction and speed (mph) of drift as determined by the hovering H-3 helicopter and surface observations.

(4). Dimensions: Seeded area and clearing dimensions based on input from ground observers, photographs, and aerial observations. Cleared dimensions apply to clearings at fog top.

ANNEX B - SUMMARY OF HELICOPTER FOG DISPERSAL TESTS

Date Mission No.	Time EDT	Fog Top-Base Ft. AGL	Fog Coverage	Prevailing Vsby. - Ft.	Fog Drift LWC mph g/m^3	Seeding Duration Amount Alt. AGL	Seeded Area Size-Location	Clearing Time Dimension Persistence	REMARKS
30 Jul. 1A	0816	700/100	OVC	E2500	SSW .112 3	Unseeded	-	1 min. 100' dia. 1 min.	In practice hover clearing patterns, H-3 cleared 100 ft. area--too small. Ground visibility fluctuated between 1000 ft. and 3000 ft. as downwash penetrated fog layer. Back and forth and expanding circles used.
1B	0835	700/100	OVC	E5000	SW .112 3	4 min. 1000 lbs. 800'	1500'x1000' 300' upwind	1 min. 200' dia. 2 min.	Drizzle area; unknown size; off target about 500 ft. across runway. Used same clearing pattern as previous test. When clearing pattern was extended beyond 200 ft. dia., worked area was donut-shaped with center slightly less dense than undisturbed fog.
2 Aug. 2A	0840	750/100	OVC	1200	SSW .038 3	Unseeded	-	2 min. 500' dia. 4 min.	Applied back and forth sweeps across target and expand expanding circles as clearing patterns. Both with same results; pilot described right circular sweeps into wind as the most comfortable maneuver.
2B	0857	800/200	OVC Small Breaks	E5000	SSW .038 5	1 min. 300 lbs. 950'	1000'x 1000' 1/4 mile upwind	2 min. 800'x1500' 8 min.	Edge of drizzle area went west and south of target; estimated to be an area 750 ft. x 250 ft. Part of cleared area was associated with natural break in fog. Seeded fog responded quicker to downwash clearing.
2C	0910 0921	800/200	BKN	E5000	SSW .050 5	3 min. 1000 lbs. 950'	1200'x3000' 1/4 mile upwind	2 min. 1500'x1500'	With considerable difficulty, located seeded area along edge of runway and short of target. With help of some natural clearing effect, was able to expand hole toward runway. This cleared area maintained itself and preceded general fog breakup by about 30 minutes.

SUMMARY OF HELICOPTER FOG DISPERSAL TESTS (CONT'D)

Date Mission No.	Time EDT	Fog Top-Base Ft. AGL	Fog Coverage	Prevailing Vsby. - Ft.	Fog Drift mph	LWC g/m^3	Seeding Duration Amount Alt. AGL	Seeded Area Size-Location	Clearing Time Dimension Persistence	REMARKS
8 Aug. 3A (White Sulphur Springs)	0750	700 / 0	OVC	600'	NE 2	-	Unseeded	-	Small Momentary Holes	Could not maintain hole more than few seconds in hover downwash.
3B	0800	700 / 0	OVC	600'	NE 2	-	10 min. 1500 lbs. 800'	2000'x1500' 200' upwind	10 min. 200' dia. (600' dia. at sfc) 2 min.	Drizzle detected at target and 2000 ft. downwind. Undissolved urea deposited in a band 200 ft. wide and 400 ft. long. H-3 was able to maintain clearing over target while seeding was in progress. At request of Airport Manager, no helicopter letdowns were attempted.
9 Aug. 4A	0950	600 / 100	OVC vrbl BKN	2250'	E 3	.013 vrbl .025	Unseeded	-	1 min. 200 ft. 1 min.	Conducted back and forth hover clearing pattern upwind edge of target to determine extent target could be kept clear as fog drifted in.
4B	1001	700 / 200	OVC vrbl BKN	2250'	ESE 3	.013 vrbl .025	9 min. 900 lbs. 800'	1200'x2700' 500' upwind	-	Drizzle occurred briefly at N end of runway. Unable to distinguish between seeded area and natural convective breaks.
4C	1033	800 / 300	OVC vrbl BKN	E 1 mi.	ESE 5	.025	2 min. 900 lbs. 800'	1200'x600' 500' upwind	3 min. 1000'x 2000' 15 min.	Using 1000' oval and figure 8 alternately, was able to keep up with fog as it drifted over runway. Natural clearing took over, with treated area over runway clearing 1/2 hour ahead of outlying areas.
10 Aug. 5A	0715	450 / 0	OVC	1535'	NE 10	.200	Unseeded 600'	-	Slight Momentary Breaks	H-3 target aircraft had difficulty holding over target area. Flight level winds estimated at 20 kts gusting to 28 kts, while surface wind was 3-5 kts.
5B	0742 to 0802	400 / 0	OVC	1900'	NE 15	.125	Two 2 min. drops 700'	3 strips approx. 1000'x500' 2500' upwind	Unorganized breaks, max 250' dia.	Drizzle occurred momentarily over target. Was unable to get organized hover clearing due to fast drifting fog and apparent shear.

SUMMARY OF HELICOPTER FOG DISPERSAL TESTS (CONT'D)

Date Mission No.	Time EDT	Fog Top-Base Ft. AGL	Fog Coverage	Prevailing Vsby. - Ft.	Fog Drift mph	LWC g/m^3	Seeding Duration Amount Alt. AGL	Seeded Area Size-Location	Clearing Time Dimension Persistence	REMARKS
12 Aug. 6A	0715	400/0	BKN	1200'	S 6-8	.038	Unseeded	-	Irregular breaks across 500' front	Conducted expanding circle clearing pattern. Could not keep up with fog drift. About 50% of fog drifted through clearing pattern.
6B	0722	450/100	BKN	1200'	S 6-8	.038	4 min. 800 lbs. 500'	1200'x2400' 1000' upwind	500' front	H-3, in expanding circle clearing pattern, was able to keep up with fog as it approached target. Fog did not reform in worked areas, although some wisps remained until natural clearing took over 30 minutes later.
6C	0735	575/100	BKN	3500'	S 6	.035	1 min. 300 lbs. 650'	2000'x2000' 1/2 mi. East of airport	-	Used figure 8 clearing pattern with H-3 on patches of seeded and unseeded fog. Few residue patches of fog remained in the treated areas. Slightly less fog remained after working seeded fog. Clearing and persistence times not available.
13 Aug. 7A	0710	400/0	OVC	1585'	SSW 6	.175	Unseeded	-	3 min. 200' dia. 1 min.	Hole had about 10° tilt.
7B	0716	400/0	OVC	2000'	SSW 6	.175	4 min. 600 lb. 600'	1200'x2400' 1000' upwind	3 min. 500' dia. 3 min.	Drizzle, followed by thinned area passed over N end of runway, 200 ft. W of target. Was able to expand area crosswind toward target. Fog moved onto target about 1 min. after clearing pattern terminated. Off-target portion closed in 2 min. later.
7C	0758	500/0	OVC vrbl BKN	1375'	S 6	.175	4 min. 600 lb. 600'	1200'x2400' 1000' upwind	3 min. 800'x1500' 15 min.	H-3 moved 1000 ft. upwind of airport and began an 800 ft. expanding oval clearing pattern. The area contained a few naturally thin spots. The elongated clearing moved across the South portion of runway.

SUMMARY OF HELICOPTER FOG DISPERSAL TESTS (CONT'D)

Date Mission No.	Time EDT	Fog Top-Base Ft.-AGL	Fog Coverage	Prevailing Vsby.-Ft.	Fog Drift LWC mph g/m^3	Seeding Duration Amount Alt. AGL	Seeded Size-Location	Clearing Time Dimension Persistence	REMARKS
13 Aug. 7D	0816	600 Unk	BKN vrbl OVC	Unk.	SW unk.	Unseeded	-	3 min. 100' dia. 1 min.	H-3 moved upwind into unseeded fog off airport and was unable to get organized clearing even though natural breaks were beginning to show.
7E	0840	600	BKN	2000'	SW .088	Unseeded	-	3 min. 200' dia. 2 min.	H-3 and CH-46 were both able to attain holes suitable for landing.
14 Aug. 8A	0737	300 0	OVC	1000' vrbl 3000'	SSW .125 5	Unseeded	-	10 min. 500' dia. 4 min.	CH-46 in short back and forth clearing pattern was able to enlarge hole to 500 ft. dia. while moving with fog drift.
8B	0750	350 0	OVC	2000'	SSW .175 3	4 min. 600 lbs. 600'	1200'x900' 300' upwind	10 min. 300'x1000' 15 min.	Drizzle started 200 ft. NW of target and lasted 5 min. Seeded fog drifted parallel to the West side of runway toward terminal building. After 15 min., hole moved out of airfield area and closed in.
8C	0918	500 100	OVC	1600'	SW .025 10	Unseeded	-	3 min. 200' dia. 1 min.	Fog lifted and became more convective in appearance. Rapidly drifting fog filled in cleared area one minute after clearing pattern terminated.
8D	0925	550 100	OVC	2000'	SW .025 6	4 min. 600 lbs. 600'	1200'x1000' 1000' upwind	5 min. 300'x500' 3 min.	At same time seeding was completed, H-3 started circular clearing pattern over the target. Could not expand hole beyond 300 ft. dia. until treated fog drifted in. Was then able to expand hole with same circular clearing pattern. Hole with some thin patches was elongated downwind.

SUMMARY OF HELICOPTER FOG DISPERSAL TESTS (CONT'D)

Date Mission No.	Time EDT	Fog Top-Base Ft.-AGL	Fog Coverage	Prevailing Vsby.-Ft.	Fog Drift LWC mph g/m³	Seeding Duration Amount Alt. AGL	Seeded Area Size-Location	Clearing Time Dimension Persistence	REMARKS
14 Aug. 8E	0946	600 100	OVC	2500'	SSW .025 0-3	4 min. 600 lbs. 700'	1200'x200' upwind	4 min. 1000'x1000' 30 + min.	Seeded fog on upwind side of natural hole as fog drifted onto target. Other natural breaks beginning to form. Was able to expedite clearing over the target 1/2 hour earlier than surrounding area.
15 Aug. 9A	0700 to 0750	350 0	OVC vrbl BKN	1100' vrbl 6000' +	SSE .275 3-5	Unseeded	-	3 min. 200' dia. 1 min.	Fog formed in well-defined bands at right angles to wind. H-3 used both figure 8 and circular clearing patterns, moving 0-20 kts. The 200ft. dia. hole applies to dense regions, while the 800 ft. dia. applies to thinner regions between bands.
							-	2 min. 800' dia. 3 min.	By moving with fog drift, helicopter was able to maintain maximum clearing with slow expanding circles clearing pattern.
9B	0820 0855	400 100	BKN	2000 ft. vrbl 6000'	SSE .100 5 vrbl .050	Unseeded	-	2 min. 400' dia. 3 min.	Worked leading edge of bands as they approached runway. Could maintain steady clearing only in thinner regions. As bands approached, patches of the 300 ft. layer passed through the clearing pattern.
9C	1010 1015	500 200	BKN vrbl SCTD	6000'	SSE .013 5	Unseeded	-	-	Natural clearing well underway. Within 5 min. was able to clear one mile slice in thin scattered fog (now low stratus). Fog did not reform in worked area.

SUMMARY OF HELICOPTER FOG DISPERSAL TESTS (CONT'D)

Date Mission No.	Time EDT	Fog Top-Base Ft. AGL	Fog Coverage	Prevailing Vsby.-Ft.	Fog Drift mph	LWC g/m^3	Seeding Duration Amount Alt. AGL	Seeded Area Size-Location	Clearing Time Dimension Persistence	REMARKS
16 Aug. 10A	0849	300/0	BKN vrbl SCTD	E1500	SW 5	.050	Unseeded	-	2 min. 500'x1500' 5 min.	Some natural breaks in vicinity of target.
10B	0852	400/100	BKN vrbl SCTD	E2500	SW 5	.025	2 min. 800 lbs. 600'	1200'x1200' 1000' upwind	2 min. 1500'x1000'	Seeded fog bank 1000 ft. NE of target. Light drizzle fallout in 7 min. Thin seeded area noted moving toward target 5 min. after drop. Pilots reported that clearing passes made in seeded fog "worked like magic," as compared with unseeded fog.
10C	0900	400/100	BKN vrbl SCTD	E2500	SW 5	.025	Unseeded	-	4 min. 500'x1000'	H-3 moved off to unseeded fog bank and noted that it took about twice as long to sweep out a 1000 ft. slice in edge of fog.
24 Aug. 11A	0722	300/0	OVC	E600	SW 5	.200	Unseeded	-	3 min. 150' dia. 2 min.	H-3 initially attempted figure 8 clearing pattern, but was able to get more organized clearing with expanding circles pattern.
11B	0732	400/0	OVC	E600 vrbl 1000	SW 3	.200	4 min. 2400 lbs. 550'	1200'x1200	3 min. 200' dia. 4 min.	Treated area drifted toward runway. 5 min after start of drop, thinner, more convective fog was observed approaching runway 22. Drizzle commenced 7 min. after start of drop, actually leaving runway with "wet" appearance. H-3 pilot noted seeded fog as being much easier to work in clearing pattern.

SUMMARY OF HELICOPTER FOG DISPERSAL TESTS (CONT'D)

Date Mission No.	Time EDT	Fog Top-Base Ft. AGL	Fog Coverage	Prevailing Vsby.-Ft.	Fog Drift mph	LWC g/m^3	Seeding Duration Amount Alt. AGL	Seeded Area Size-Location	Clearing Time Dimension Persistence	REMARKS
24 Aug. 11C	0758	500 100	OVC vrbl BKN	E1500	SW 3	Unk	4 min. 800 lbs. 500'	1200'x1000'	5 min. 3000' dia. 5 min.	While seeding application was much lighter than previous run, seeded fog tops showed characteristic convective appearance with thinned-out areas between. The large clearing was about 20% wisps of fog, but not enough to prevent H-3 maneuvering and let down.
25 Aug. 12A (White Sulphur Springs)	0820	550 0	OVC	E1000	WSW 4	Unk	Unseeded	-	4 min. 150' dia. 1 min.	H-3 was able to get small organized clearing with back and forth hover clearing pattern, alt. variable 100 ft. above fog top to 50 ft. below. Unable to get organized clearing with figure 8 pattern.
12B	0817 to 0830	350 1	OVC	2500	SW 3	Unk	Unseeded	-	5 min. 175'x300' 2 min.	Hole elongated downwind as H-3 conducted hover clearing pattern from 700 ft. AGL.
12C	0849 to 0900	700 1	OVC	2500	SW 3	Unk	Unseeded	-	7 min. 2000'x3000' 5 min.	CH-46 and H-3 flew formation clearing pattern in expanding circles. Positive cleared area achieved with about 25% of fog remaining. Pilots experienced difficulty in hold formation at low air speeds.
26 Aug. 13A	0718	200 vrbl 300 0	OVC vrbl BKN	E400	SW 3	.148	Unseeded	-	3 min. 200'x500' 2 min.	H-3 used circular hovering clearing pattern with good results on thickening fog.

SUMMARY OF HELICOPTER FOG DISPERSAL TESTS (CONT'D)

Date Mission No.	Time EDT	Fog Top-Base Ft. AGL	Fog Coverage	Prevailing Vsby.-Ft.	Fog Drift mph	LWC g/m^3	Seeding Duration Amount Alt. AGL	Seeded Area Size-Location	Clearing Time Dimension Persistence	REMARKS
26 Aug. 13B	0749	$\frac{300}{0}$	OVC vrbl BKN	E400	SW 3	.125	2 min. 1000 lbs. 400'	1200'x600' 1000' upwind	3 min. 200'x200' Unknown	No drizzle occurred on field and at no time were observers able to agree on which direction the seeded area appeared. Hover clearing pattern was conducted over the target, but could not verify the fog as having been from the seeded area.
13C	0810	$\frac{350}{0}$	OVC vrbl BKN	E500	SSW 2	.085	2 min. 800 lbs. 400' (encapsulated urea)	1200'x600' 300' upwind	-	Again could not positively identify seeded area. H-3 conducted clearing pattern on two areas North and West of the target. Natural breaks becoming more numerous throughout the area. Mission terminated due to helicopter mechanical and radio problems.

ANNEX C

SUMMARY OF CAPE COD FOG DISPERSAL TEST FLIGHTS

March - April 1972

Test No.	Date/Time	Dispenser Pod	Total Amount	Fog Characteristics	Seeded Area Size - Location	Seeding Rate - Alt.	Remarks
1	30 March 10:30	External Pod #1	Sierra Urea (1971 Roanoke) 1000 lbs.	VFR	Nantucket, Figure 8 Lateral dist. 1000 ft. 1/2 mi. upwind Rwy 33	(2) 1 min. drops 500 lb/min. 900 ft. AGL	Flow and texture of Sierra material excellent after retention in the pod since Lewisburg Project, August 1971.
2	31 March 09:00	External Pod #1	600 lbs. Sierra	VFR	Over water en-route Nantucket to Otis AFB	(2) 30 second drops, variable rate	Pilot/dump crew coordination training.
3	4 April 09:40	External Pod #2	1600 lbs. Sierra	VFR	Nantucket: Fig. 8 lateral dist. 1000 ft. 1 mi. upwind of Rwy 33	(3) 1 min. drops 500 lb/min. & 250 lb/min. 600 ft. AGL	Pod #2 (50 cubic feet) swayed at airspeeds in excess of 70 knots. Much less stable than the heavier 66 cubic ft. pod.
4	5 April 10:30	Internal Pod #3	1000 lbs. Sierra	VFR	Nantucket, Fig. 8 1/2 mi. upwind & 1/4 mi. upwind of Rwy 06	(3) drops at varying altitudes: 500 lb./min. & 250 lb/min.	Targeting practice. Photography & observers confirmed direction was good. Distance of fallout very erratic due to gusts & unstable air.
5	6 April 10:15	Internal Pod #3	1500 lbs. Sierra	VFR	Over water: Fig. 8 1000 ft. lateral distance	(3) 1 min. drops 500 lb./min. 900 ft. AGL	Plume measurements and particulate measurements with Cessna 401. Pod loading ramp remodeled.
6	10 April 11:30	Internal Pod #3	1200 lbs. Sierra	VFR	Over water: straight line release	(2) 2 min. drops 600 ft. AGL Flow erratic.	Repeat of Nephelometer measurements in plume at and 300 ft. below release altitude. Flow problem due to faulty aerator connection.

Test No.	Date/Time	Dispenser Pod	Total Amount	Fog Characteristics	Seeded Area Size - Location	Seeding Rate - Alt.	Remarks
7	12 April 06:00	Internal Pod #3	1600 lbs. Sierra	-X3●7/8F 650 ft thick	Otis AFB, Fig. 8, 1200 ft. lateral dist., 1/4 mi. upwind of Taxiway "J"	(1) 3.3 min. drop 500 lb/min 1000 ft. AGL	Excellent clearing action over Rwy 05. CH-46 landed in artifically cleared area. See complete case study Annex D.
8	13 April 06:30	External Pod #2	1200 lbs. Sierra	VFR Scattered stratus south of Otis	Over water south of Otis AFB; Fig. 8, over thin drifting stratus	(2) 1 min. drops 500 lb/min. 1000 ft. AGL	Not evaluated due to rapid natural clearing.
9	13 April 09:45	Internal Pod #3	800 lbs. NCR	VFR	Nantucket; Fig. 8, Lateral dist. 1000 ft. 1 mi. upwind of Rwy 06	Erratic flow 600 ft. AGL	Left delivery tube clogged. Targeting direction good.
10	15 April 08:45	Internal Pod #3	1200 lbs. NCR	VFR	Nantucket, Fig. 8, Lateral dist. 100 ft. 1 mi. upwind of Rwy 06	4 min. drop 300 lb/min. 900 ft. AGL Pod pressure fell to 3 psi	Targeting direction good. Intentional overshoot due to strong winds. Urea deposits found on target helicopter. Flow erratic.
11	16 April 06:30	Internal Pod #3	1500 lbs. NCR	Scattered low stratus at Nantucket	Nantucket; Fig. 8, 1/2 mi. upwind of Rwy 06	3 min. drop 500 lbs/min. 500 ft. AGL	Material collected at target area showed evidence of growth. Not evaluated due to thin, fleeting nature of stratus.
12	18 April 10:30	Internal Pod #3	1600 lbs. NCR	VFR	Nantucket, Fig. 8, 1 mi. upwind of Rwy 06	(3) 1 min. drops & 1 cleanout burst. 550 lb/min.	Clogging of 1 tube occurred. Was cleaned out in flight, otherwise excellent plume dispersion with NCR urea.
13	20 April	Internal Pod #3	NCR (recycle)	(Ground test of flow through delivery tubes)			Clogging problem solved by replacing steel tubes with smooth seamless PVC.

ANNEX-D

CASE STUDY

Fog Dispersal Test, 12 April 1972

1. FOG CHARACTERISTICS

a. Weather Summary

Shortly before midnight, 12 April 1972, the visibility at both Nantucket Airport and Otis Air Force Base decreased to less than 1 mile, with surface winds out of the north-northwest, 3 to 5 knots. Temperatures were in the middle 30's with a temperature dewpoint spread of 1°F. At 04:00 EST the Nantucket winds increased to 8 knots and shifted to the north-northeast. This wind shift was accompanied by drying in the lower levels and a rapid increase in visibility. The Cessna 401 observation made at 05:56 confirmed the fog break-up over the islands and adjacant waters. At Otis AFB (alternate fog target) the visibility continued below 1 mile. Accordingly, the decision was made to conduct operations on the fog and low stratus at Otis. Helicopter lift-off was scheduled for 06:00 EST. The prevailing surface weather at 05:56 was; thin obscuration, ceiling 300 feet overcast, visibility 7/8 mile in fog, temperature 33°F, dew point 30°F, wind 010° 4 knots. The target and seeder helicopters lifted off at 06:01, reporting the base of the overcast stratus at 250 feet and tops at 900 feet MSL. Figure D-1 shows the temperature and moisture distribution in the lower layer as determined from aircraft observations and the 12:00 GMT radiosonde.

2. DESCRIPTION OF TEST

a. Observation Aircraft

At 06:00 the Cessna observation aircraft flying in the Otis

area verified the stratus tops at 900 feet MSL and slightly convective in appearance. Clearance was given to continue the test without delay.

b. Downwash Clearing in Unseeded Stratus

The target helicopter proceeded immediately to a hover position 100 feet above the stratus tops, using the ELF and Otis Radar to maintain its position over the taxiway "J" fog target. At 06:10 prior to seeding, a series of hover downwash clearing patterns were performed, but useful clearings were not attained.

c. Downwash Clearing in Seeded Stratus

(1) While the target helicopter was conducting clearing test in unseeded stratus, the CH-46 seeder, equipped with the internal dispenser and Sierra unsized urea, proceeded to the designated drop position 1/4 mile upwind of the target helicopter. At 06:12 the seeder was established in a "figure 8" pattern. By 06:20 the unseeded stratus tests were completed and the stratus had re-stabilized so that the seeding test could begin.

(2) The urea drop began at 06:22 from an altitude of 1000 feet AGL, continuing for 3.3 minutes at 500 pounds per minute. The lateral distance across the pattern was 1200 feet, airspeed 30 knots. The seeded layer of stratus drifted toward the target at 6 knots where the characteristic greyish, thinned appearance of seeded fog was noted by the target helicopter pilots. Four minutes after the drop began, drizzle was reported by ground observers at the ELF radio location and the helicopter parking ramp (See Figure D-2).

(3) At 06:25 the target helicopter began a series of hover

clearing patterns at the top of the seeded layer, and within 3 mimutes a clearing approximately 1200 feet in diameter was produced. The CH-46 target helicopter experienced no difficulty in making a visual descent through the induced clearing. Table D-1 is a sequencial log of events reported by observers during the test. Table D-2 is a summary of certain data pertaining to the test, and Figures D-3 through D-10 are photographs taken from the Cessna 401 during the clearing operation.

d. Drizzle Fallout Area

At 06:24 the ELF ground radio operator positioned at taxiway "J" detected the characteristic drizzle produced by hygroscopic seeding. This was followed by reports of observers of similar drizzle at the helicopter ramp and outside the Base Operations building. Later in the day, when the induced drizzle dried on smooth surfaces such as auto windshields and taxiway lights, it was possible to identify the extent of the drizzle fallout area. The area in which the fallout was detected is shown in the airport diagram of Figure D-2.

3. DISCUSSION OF RESULTS

a. Dimensions of the Cleared Area

(1) Airborne observation and photographs taken during the test on 12 April show that the broad and relatively shallow downwash of the twin rotor CH-46 was unable to penetrate the full depth of the 650 foot stratus layer. Thus visual contact with the ground could not be made through the unseeded stratus.

(2) When the clearing patterns were conducted above the layer of seeded stratus the downwash was much more effective. As in previous tests, pilots were able to

identify the seeded area by its characteristic grayish appearance, and after three minutes of hover clearing turns, produced a clear area approximately 1200 feet in diameter. In this case the cleared area drifted with the 5-6 knot wind for 8 minutes before it closed in due to natural turbulent processes.

(3) While it is not appropriate to draw firm conclusions from this single test of the helicopter seeding of low stratus, it is interesting to note that the clearing results were much the same as those obtained in the Lewisburg, West Virginia radiation fogs.

b. Seeding Concentration Computations

The unsized urea seeding material used in these applications had an average particle size of about 25 micron diameter, with 90% passing through a 200 mesh (74 micron) screen. Anti-caking and fluidizing additives maintained the active urea crystals in a stable state so they could be stored indefinitely in the pressurized pods, yet be in readiness for seeding applications.

In the test of 12 April, the helicopter dispenser valve was operated in the full open position, giving an application rate of 500 pounds per minute. Seeding material was applied at this rate for 3.3 minutes in a figure eight delivery pattern, 30 knots air speed, across a lateral distance of 1200 feet. Fog was drifting through this seeding pattern at 6 knots (600 feet per minute).

With the seeding pattern described above, 500 pounds of dispersant was applied to a stratus area 1200 feet by 600 feet each minute. Converting these dimensions to metric units, the seeding concentration can be stated as:

$$\frac{227 \times 10^3 \text{ grams}}{366 \text{ meters} \times 183 \text{ meters}} = 3.4 \text{ grams per square meter}$$

This rate is within the general order of magnitude specified in hygroscopic seeding studies by Cornell Aeronautical Laboratories (Kocmond and Jiusto, 1968), Air Force Cambridge Research Laboratories (Silverman and Kunkle, 1970), and the nomograms developed in the earlier Marine Corps tests.

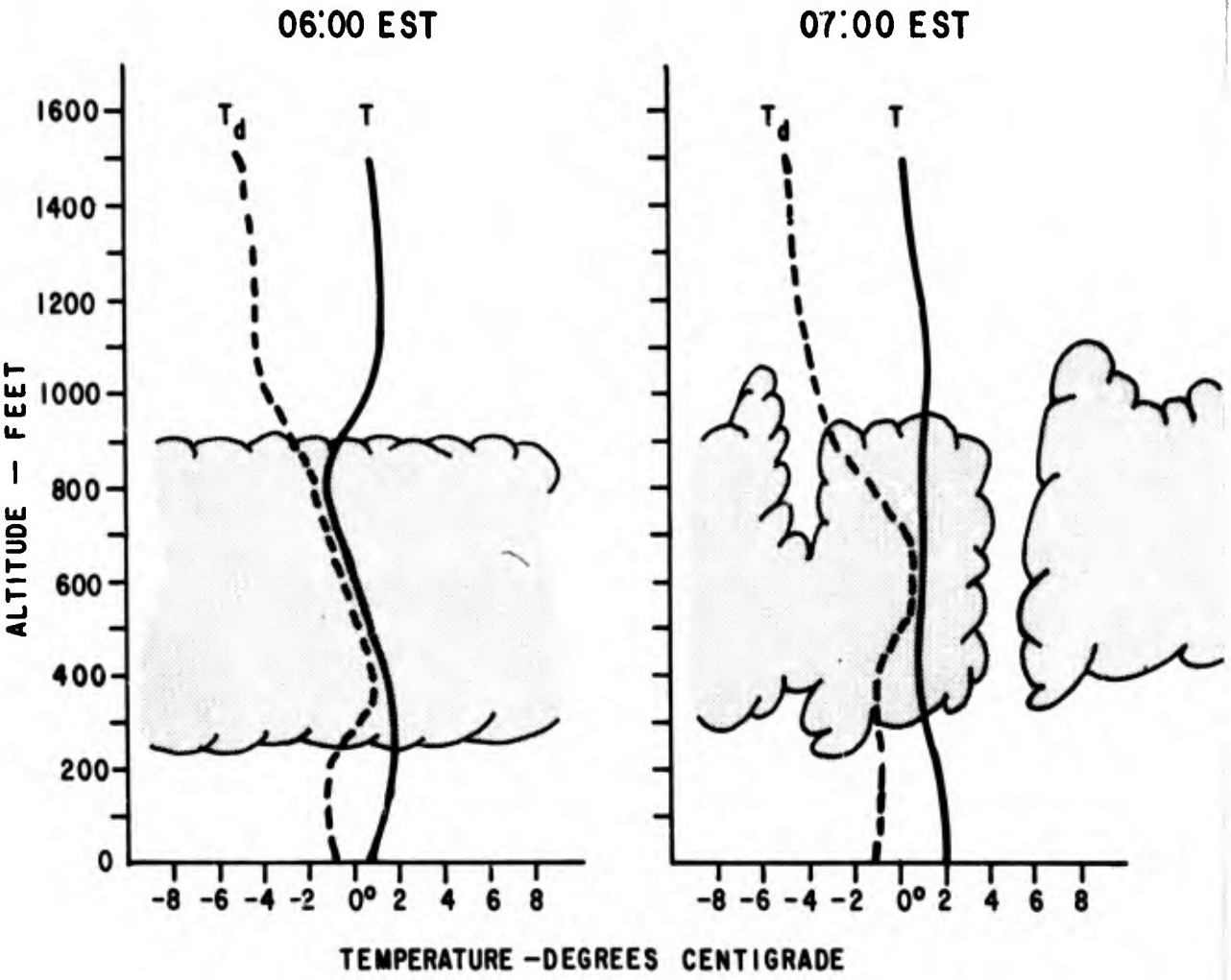


Figure D-1. Temperature (T) and dew point (T_d) distribution curves constructed from the 12:00 GMT radiosonde and Cessna 401 aircraft soundings made before and after the 06:20 EST stratus dispersal test.

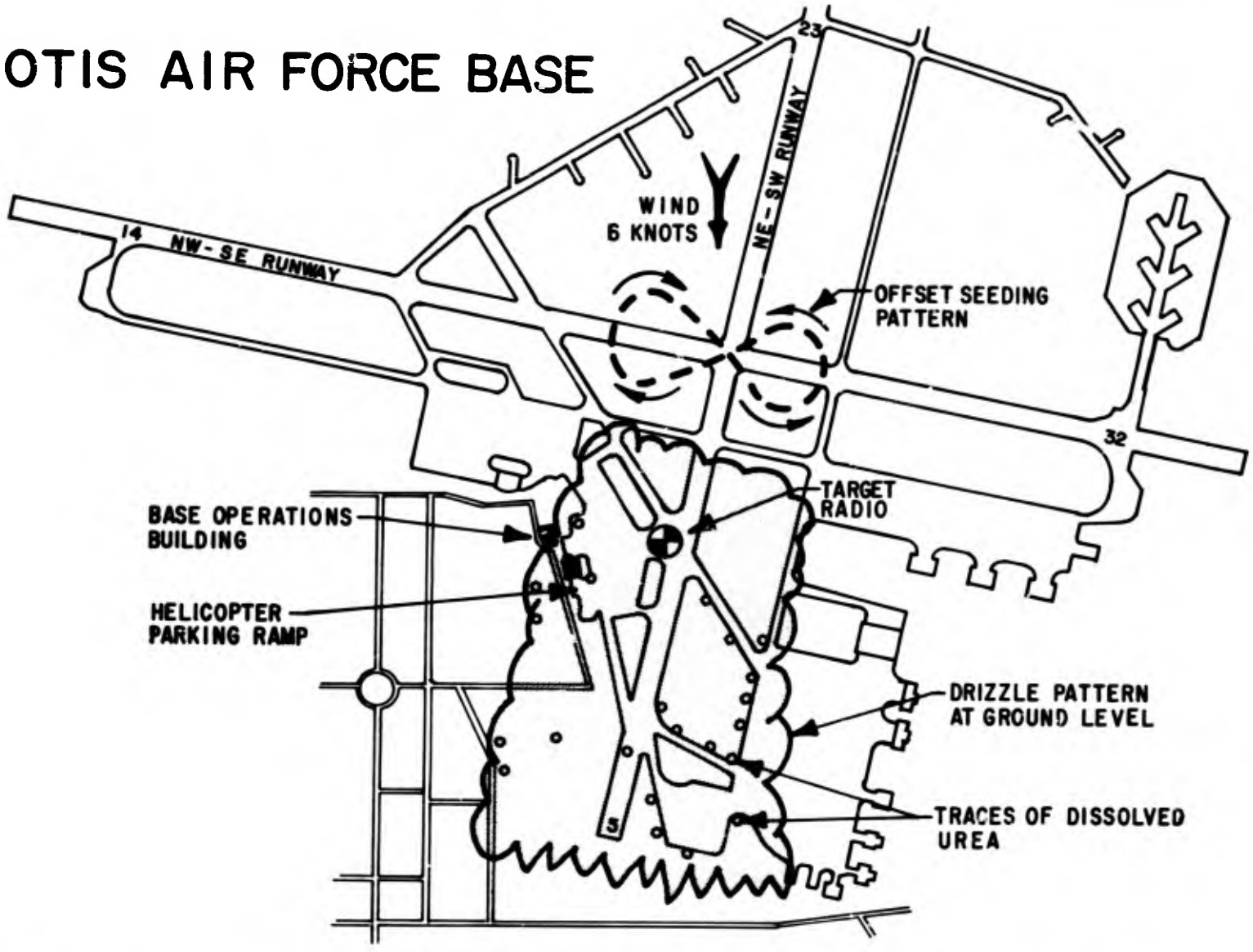


Figure D-2. Seeding Pattern and Drizzle Area Produced in the 12 April Test. From the offset position, 1/4 mile upwind of the target, the seeder helicopter released seeding material along a 1200 foot figure 8 pattern. Airspeed in the seeding pattern was 30 knots.

Figure D-3 (06:10) Two CH-46 helicopters above the 650 foot layer of stratus clouds. The cloud base was 250 feet above ground level, tops 900 feet and slightly convective. The target helicopter (ELF) in the upper left portion of the photo has just completed a downwash clearing pattern (before seeding). The hover downwash produced troughs in the fog, but clearing did not extend through the full depth of the cloud layer.

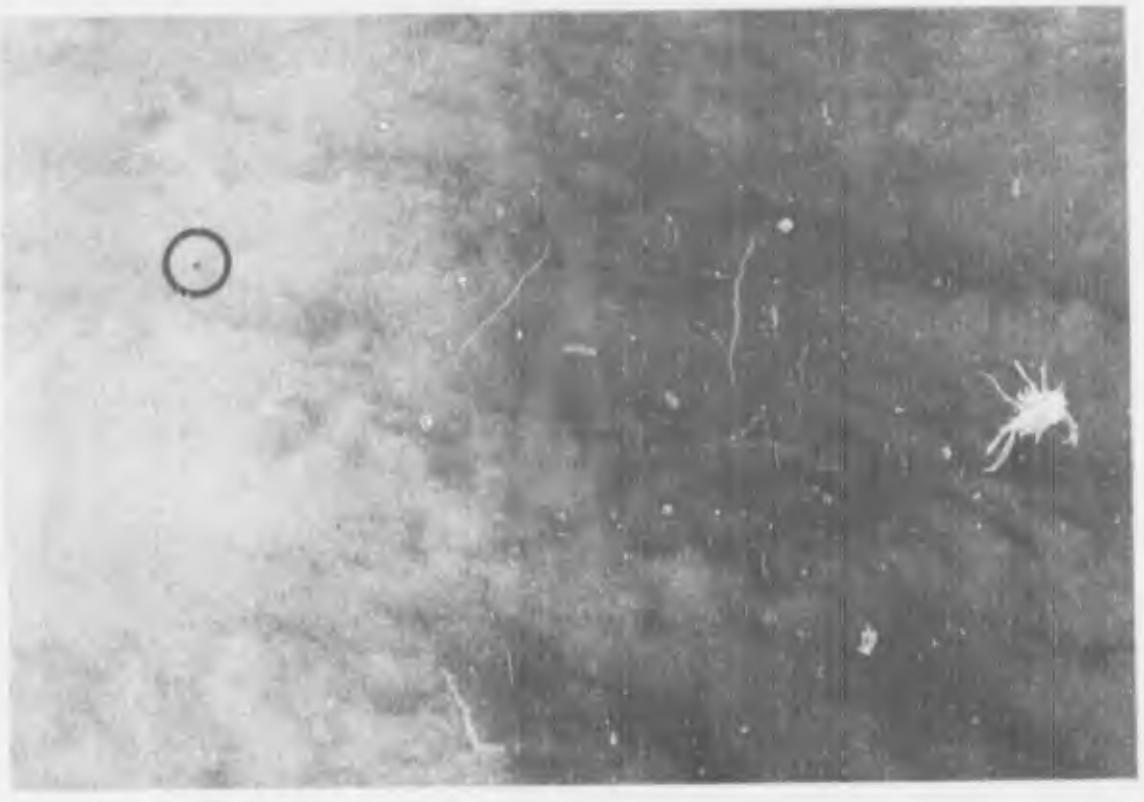


Figure D-4. (06:20) View of stabilized stratus tops as seeding began 100 feet above cloud tops. Seeding plume can be seen penetrating the layer; air speed 30 kts, penetration depth 300 feet.

Figure D-5. (06:22) Seeding continuing in a figure 8 pattern, 1200 feet lateral distance, 1/4 mile upwind of the target.

Figure D-6. (06:23) Photograph taken 30 second before seeding was terminated. Seeding rate was 500 pounds per minute; duration of seeding was 3.3 minutes.

Figure D-7. (06:27) CH-46 conducting a clearing pattern in the seeded stratus.

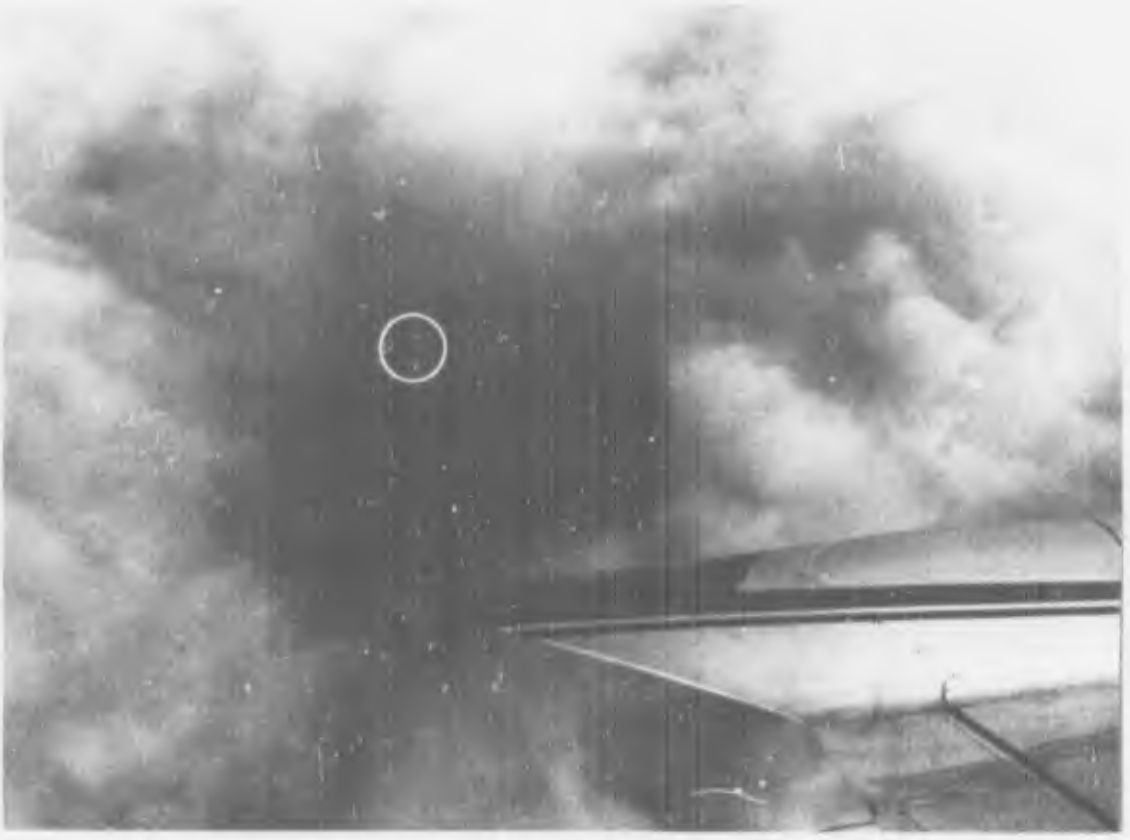


Figure D-8. (06:28) CH-46 descending through the induced clearing, 1200 feet in diameter.

Figure D-9. (06:30) View of the induced clearing as it drifted southwestward over Runway 5.

Figure D-10. (06:31) The artificially induced clearing persisted for approximately 8 minutes, after initial clearing was attained.

TABLE D-1

MISSION SUMMARY

Date: 12 APR 11 Test No. 8 Pod Load: 1700 lbs SRC UREA

Seeder Helicopter: MX-21 MAJ. COLLINS, CAPT. MARKS, GROSS WT. 23,000

Target Helicopter: MX-19 CAPT. AGTEL, CAPT. SMITH, GROSS WT. 21,000

Prevailing Weather: (Local Standard Time)

06:00 -X3 @ 7/8F 010°/4 Kts. 33°/30°

06:23 -X3 @ 1½F 010°/3 Kts. FOG DISPERSAL B 06:10

07:00 -X3 @ 1½F 010°/6 Kts. FOG DISPERSAL E 06:45

Fog Characteristics:

Top: 900 ft. AGL Base: CESSNA 401 AIRCRAFT CEILING 250 ft. AGL

Vsby: 1 mile LWC: estimated 200 g/m³ Movement: SSW 5 Kts.

Location of Seeder: ¼ mi UPWIND OF TARGET, 100 FT ABOVE FOG TOP

Release Pattern: FIG 8, 1200 FT LATERAL DISTANCE, 25-30 KTS.

Release Time: (1) 06:20-06:23 (2) _____ (3) _____

Release Rate: 500 lbs. PER MINUTE Total Drop: 1600 lbs (3.3 MIN)

Remarks:

1. RELEASE MADE WITH FULL VALVE, PRODUCING EXCELLENT PLUME IN FULL ROTOR WAKE. POD PRESSURE HELD STEADY AT 5 PSI FOR 3 min., DROPPING RAPIDLY TO 1 PSI DURING LAST 20 SEC. OF THE DROP.

2. DRIZZLE DETECTED AT TARGET RADIO NEAR TAXIWAY "J" and in FRONT OF AERO CLUB HANGER -- 4 MINUTES AFTER DROP.

3. BOUNDARY OF DRIZZLE PATTERN WAS EASILY IDENTIFIED ON CAR WINDSHIELDS AND TAXIWAY LIGHTS (SEE RUNWAY DIAGRAM.)

4. CH-46 (MX-19) PRODUCED A CLEARING 400 YARDS IN DIAMETER, AND DESCENDED FOR A LANDING AT 06:29.

TABLE D-2

OBSERVER GROUND NOTES

05:00	Nantucket (ACK) observation: 7 3 F 33°/32° 360°/08kts,
05:40	Cessna 401 takeoff Otis; fog breaking up to south and east.
05:45	Otis AFB (FMH) observation: -X⊕3 1/2 F 010°/06 kts.
05:45	ELF target radio set up at taxiway "J", Otis AFB
06:00	FMH observation: -X⊕3 7/8F 010°/04 33°/30°
06:00	ACK observation: -X ⊕4 F 35°/52° 010°/08 knts.
06:01	Helicopters lift-off; MX-19 (ELF), MX-21 (Seeder)
06:05	Hear helicopters above; ELF look on.
06:10	ELF helicopter reported downwash trough; unable to see ground.
06:18	MX-21 gave 10 sec. warning for first drop.
06:19	MX-21 reported no flow on first try; had to give back pressure on dump valve.
06:20	Seeder helicopter reported dump valve full open; flow steady, plume excellent.
06:23	FMH weather observation: -X⊕3 11/2F 010/08ft; fog dispersal began 06:10.
06:23	Seeder helicopter reported flow surging, pod almost empty.
06:24	Drizzle noted at ELF ground radio and on helicopter parking ramp.
06:25	ELF pilot noted thinning of seeded fog layer below; commenced back and forth clearing pattern in seeded fog.
06:25	Drizzle ended at ELF ground radio.
06:26	Large slightly elongated clearing over the runway; estimated 300 yards in diameter.
06:28	Maximum hole attainable 400 yards. ELF helicopter easily made visual let down and landing through cleared area.
06:29	MX-19 on ground taxiing to ramp.
06:30	Large hole above parking ramp drifting southwest.

06:35 Began check of runway for evidence of treated drizzle. Unable to find dissolved urea at intersection or in vicinity of control tower.

06:38 Taxiway "G" no trace of dissolved urea.

06:40 MX-21 made GCA letdown.

06:40 Urea stain noted along approach end of runway "5"; also on buildings and taxiway lights to the north of the barrier line.

06:40 Fog dispersal termination message passed to Base Weather.

06:45 No fallout at National Guard hanger. Trace on flood lights at Base Operations. Trace on Base Operation pick-up truck. Trace on cars in parking lot north of helicopter hanger. Beer cans in wooded area southwest of runway "5" showed trace of dissolved urea. Trace also noted near runway "5" inactive transmissometer and taxi lights on ramp south of runway "5" touchdown point. No trace at control tower.

07:00 FMH surface observation: -X⊕3 11/2 F 060°/06 kts. 34°/32°, Fog dispersal ended 06:45.

07:17 FMH surface observation: -X4⊕V⊕5F

07:20 Rapid natural clearing continuing.