UNCLASSIFIED

AD NUMBER

AD874515

NEW LIMITATION CHANGE

TO

Approved for public release, distribution unlimited

FROM

Distribution authorized to U.S. Gov't. agencies and their contractors; Critical Technology; AUG 1970. Other requests shall be referred to Naval Air Systems Command, Attn: NMC, Washington, DC.

AUTHORITY

USNWC ltr, 30 Aug 1974

THIS PAGE IS UNCLASSIFIED

NWC TP 4929
COPY 197

PROJECT FOGGY CLOUD I

by

E. Alex Blomerth
White Sands Missile Range

R. S. Clark
H. E. Cronin
J. R. Ennis
R. L. Lininger, MAJ, USAF
D. W. Reed, CAPT, USA
P. St.-Amand
W. C. White
T. L. Wright
Research Department

ABSTRACT. Foggy Cloud I was a series of experiments in observation, modification, and treatment of fog and stratus clouds conducted at or near the Arcata-Eureka airport, Humboldt County, Calif., from late March through mid-November 1968.

Civil and military personnel from the Navy, Army, and Air Force participated in the experiments, aided by contractor personnel and local representatives of the Federal Aviation Administration, National Bureau of Standards, Humboldt County Director of Aviation, and the Coast Guard.

A wide range of prospective seeding agents, including smokes, liquids, and powders, that were thought to offer promise for stabilization or clearance of fog were systematically screened by ground-based and airborne dissemination. The major emphasis was placed upon the elimination of fog rather than upon simply improving visibility.

Those agents showing enough identifiable effects to indicate promise were investigated in detail and improved upon. Observations were made of fog characteristics, visual effects, changes in cloud physics parameters, and of the fallout from the fog.

Hygroscopic smokes were found useful for intensifying, stabilizing, and forming fog and stratus. Hygroscopic powders, including sodium chloride, urea, and calcium chloride, were tried. Of these, calcium chloride showed the most promise, but testing was not completed.

Hygroscopic liquids showed the most immediate results and successful tests were made with ammonium nitrate in solution. In October, a solution consisting of ammonium nitrate, urea, and water was developed that was used in several very successful field trials.

NAVAL WEAPONS CENTER
CHINA LAKE, CALIFORNIA ✱ AUGUST 1970

85

NAVAL WEAPONS CENTER
AN ACTIVITY OF THE NAVAL MATERIAL COMMAND

M. R. Etheridge, CAPT, USN .... **Commander**

H. G. Wilson .... **Technical Director**

FOREWORD

Project Foggy Cloud is a continuing research and development program conducted by the Earth and Planetary Sciences Division of the Research Department, Naval Weapons Center, under AIRTASK A370-5401/216C/OW 3712-0000, Atmospheric Applications, from AIR-540, Naval Air Systems Command.

The first field project in warm fog modification (Foggy Cloud I) began 25 March 1968 and ended 15 November 1968. Seventy-two tests were performed. A primary objective for this initial series was the screening of a broad variety of materials and methods to identify those that justified more detailed efforts later. From the results reported herein, a choice can be made of promising leads for future work.

This report is released at the working level. Because of the continuing nature of the warm fog research program, tentative conclusions presented here are subject to later review and change.

Released by
PIERRE ST.-AMAND, *Head*
Earth and Planetary Sciences Division
1 April 1970

Under authority of
HUGH W. HUNTER, *Head*
Research Department

NWC Technical Publication 4929

Published by .... Publishing Division
Technical Information Department
Collation .... Cover, 42 leaves, DD Form 1473, abstract cards
First printing .... 270 numbered copies
Security classification .... UNCLASSIFIED

CONTENTS

SUMMARY

From March to mid-November 1968, the Earth and Planetary Sciences Division of the Naval Weapons Center; the Atmospheric Physics Division, White Sands Missile Range, (Army); the Air Force Cambridge Research Laboratories; and the Navy Weather Research Facility, working with Arcata, Calif., units of the Federal Aviation Administration, the National Bureau of Standards, and the Coast Guard, conducted Project Foggy Cloud I. This project mainly evaluated techniques and materials to modify warm fogs and low stratus clouds. The project was based at the Arcata-Eureka airport in northern California where several such projects have been conducted in the past.

In all, 72 seeding tests and 41 supporting tests were run. Three classes of seeding agents were tested: (1) pyrotechnic units, including four kinds of airborne fusees and four other kinds of ground-based units; (2) hygroscopic powders dispensed from one or two aircraft; and (3) hygroscopic solutions dispensed in one test from a ground-based spray system and in all other cases from one, two, or three aircraft. The supporting tests yielded information on various properties of the local natural fog conditions or on aspects of the seeding and data-taking techniques used in the test series.

An analysis team was attached to the project. On-site analysis established a feedback of results on the basis of which subsequent tests were planned. Thirteen progress reports were prepared by the team. These reports were given only limited distribution outside NWC and other groups directly involved.

A variety of seeding-aircraft patterns were employed, with no single pattern emerging as conclusively superior. In most cases, the seeding patterns were flown skimming the top of the cloud or fog layer. Patterns were based on existing airport navigation aids, or on control by either radar or topside aircraft during tests away from the airport. Other supporting aircraft provided cloud-physics data, as well as photographic and visual observations, during the tests.

Large amounts of routine and special data were gathered both with existing airport instrumentation and with special devices furnished by the project organizations. Data-gathering techniques were augmented and improved continuously throughout the project, and specific further refinements are recommended for future projects. Project data for each test are filed at NWC.

The airborne pyrotechnic units gave no clear results. Ground-burned pyrotechnics sometimes produced partial clearing, but usually intensified the fog and on occasion produced a stable fog or stratus in previously clear air.

The hygroscopic powders were not tested extensively enough to warrant conclusive comparisons, but urea and calcium chloride appear promising. Possibly because of inadequate dosage, no tests with hygroscopic powders yielded results on a scale large enough to be termed operationally significant.

The most promising tests were those using a newly developed hygroscopic solution. This solution consists, by weight, of 4 parts ammonium nitrate, 3 parts urea, and 0.78 part water, giving a solids-to-water ratio of 9:1. This material is judged more effective than single-solute solutions of ammonium nitrate, urea, calcium chloride, or sodium chloride. The 9:1 solution is intensely hygroscopic, beneficial to plant life, and noncorrosive to most metals (except copper and cadmium), protected surfaces, and animal tissues.

Twelve tests were run with the 9:1 material, using a variety of seeding techniques. One of these 12 was ground-based, and failed because of clearly inadequate dosage resulting from mechanical failure

in the seeding spray device. Two of the remaining 11 tests were conducted with small, warm cumulus clouds, which dissipated rapidly following the treatment. The other 9 tests used the material dispensed in 650- to 2,700-gallon amounts by one to three aircraft in warm stratus or fog. Two of these 9 tests were inadequately observed to allow conclusive analysis of results, but the remaining 7 included 3 tests in which dramatic, operationally useful clearings are attributed to seeding.

The extent of dispersal to be expected from airborne use of this material depends, in yet-unknown ways, on interrelations between the amount of material used, size of spray droplets, flight patterns, and various characteristics of the target cloud or fog. Further research is needed to produce an optimized and reliable fog-clearing technique.

INTRODUCTION

THE PROBLEM

The deleterious effects of fog and low stratus on military activities are well known. Any capability to modify unfavorable weather has potential benefits for many segments of the military and civilian community; fog dispersal is a particularly attractive goal. Efforts at Arcata were concentrated upon clearing of fog and stratus rather than improvement of visibility by changing drop sizes.

Fog and stratus differ, by definition, in the altitude of their bases, fog being based at or very near the surface. Fog and stratus clouds differ in the mechanism of genesis and development, in the degree of stability above and below the cloud tops, and in the radiational and meteorological regimes in which they occur and to some extent in the microphysics. It is only an accident of topography that clouds touch the ground, and a definition of fog on this basis is not very useful in terms of understanding the regime. Indeed the treatment required for fog and for stratus may differ because of the inherent differences in the cloud type. It is well to keep this distinction in mind even though the two phenomena are sometimes treated as one.

Fog and stratus that occur at temperatures above 0°C are termed "warm." Similar clouds of liquid water occuring at temperatures below 0°C are termed supercooled or "cold." Supercooled clouds can be modified easily on an operational basis. Dissipation of warm fog has been much more difficult. Project Foggy Cloud was conducted to investigate ways to solve this problem.

PROJECT GOALS

The goals of Project Foggy Cloud were to

1. Test potential agents for fog dissipation or intensification
2. Improve seeding and dispersal techniques
3. Improve data collection and analysis techniques

These goals support the ultimate objective: seeding methods capable of operational warm fog dissipation or intensification under specified conditions.

PREVIOUS METHODS OF TREATING WARM FOG

Research and development activities to modify warm fog have been conducted for more than three decades. The classical works with sprayed calcium chloride solution pointed a way to fog clearance (Ref. 1). Nevertheless, the concepts of hygroscopic treatment to dry fog were not sufficiently developed in ensuing years to generate a reliable system.

During World War II, the heavy traffic of military aircraft at fog-bound bases in the United Kingdom led to the development and use of drying by thermal systems the direct application of the heat of combustion of petroleum fuels. Although this method (called FIDO) did clear fog, there are many drawbacks, including immobility, cost, maintenance, pollution by smoke and water vapor, and the hazards of open flames near runways. Better-engineered FIDO installations were tested with good results after the war (e.g., at Arcata, Calif., 1948). The use of jet engines as a heat source has also been tested with varying results in warm fog. Although engineering developments might remove some of the drawbacks of a thermal system, one fundamental limitation remains. Each site where fog clearance is needed would require its own installation. Under most tactical conditions in the field, a capability is needed to take the treatment to the fog.

Junge (Ref. 2) surveyed the state of the art in fog dispersal to 1958. He commented on both field-tested methods, including FIDO, and those that even now remain in the category of untried ideas. An updated, critical review of fog dispersal theory and practice is badly needed. The remarks in this section are intended only to point out a few highlights in the rapidly expanding efforts to fight warm fog.

Warm fog research and development efforts have multiplied significantly in the last decade. Fundamental studies of the properties of natural fog and computer modeling of fog-dispersal methods have been developed. A number of field tests have evaluated fog-seeding or alternative dispersal methods. Once calibrated with representative numbers by field experimentation, computer modeling offers great promise to investigate fog-seeding effects under a wide range of meteorological conditions. Realism in numerical modeling demands great complexity, because the interaction of physical processes is itself complex. Nevertheless, progress is being made in computer studies at Desert Research Institute, Cornell Aeronautical Laboratory, Navy Weather Research Facility, and Air Force Cambridge Research Laboratories. These agencies furnished technical advice or assistance in the performance or understanding of some aspects of the work reported herein.

Most of the field-trial emphasis has been placed recently on the use of hygroscopic seeding materials dispensed from aircraft or from ground-based units. After a distillation of theoretical and experimental work, the fog-modification community has largely discarded nonhygroscopic agents (e.g., carbon black, surfactants, charged inerts) as materials with which to treat existing warm fogs. Including Project Foggy Cloud, no fewer than five field projects have been conducted with hygroscopic agents in the United States since the beginning of 1968 (by Air Weather Service, Cornell Aeronautical Laboratory, Cambridge Research Laboratories, E.G.&G. Associates, and Naval Weapons Center). There may be others; only a few reports have been published (Ref. 3 and 4), and the materials used in the tests sponsored by the Airline Transport Association[1] at Sacramento have not been disclosed because they are proprietary.

SELECTION OF SITE

The project was based at the Arcata-Eureka airport, McKinleyville, Calif. (Fig. 1). Most of the experiments were conducted over the airport or in a specially designated area offshore (Fig. 2). The remaining tests were run either in remote areas over land or, in one case, by special arrangement at Medford, Ore. In addition to having a high frequency of advective fog and stratus, Arcata was a suitable choice for several other reasons: space was available for offices, conferences, and briefings; although not a heavily used airport, Arcata has radio, navigation, and instrument landing system equipment; other nearby airports provide safe landing alternates when Arcata has below-minimum weather; the airport has a special network of transmissometers (Fig. 3) that provide data useful in evaluating test results; and personnel of the National Bureau of Standards, Federal Aviation Administration, and the Humboldt County Department of Aviation at the airport are extremely cooperative in supporting projects of this type.

Fog generation at Arcata is controlled by the season of the year and the wind flow patterns. As shown in Fig. 4, taken from National Bureau of Standards Report 9958 (Ref. 5), the greatest incidence is during summer months. Moisture-laden air advects from the sea when the airflow pattern is from the southwest to northwest. "Onshore" flow is aided during the warm summer months by

[1] Naval Weapons Center. *Observation and Interpretation of Airline Warm Fog Dispersal Tests at Sacramento, California, 5 January to 29 February 1968*, by T. L. Wright. China Lake, Calif., NWC, August 1968. Preliminary Report.

FIG. 1. Arcata-Eureka Airport.

the presence of a seasonal thermal low system that forms over the hot inland desert and mountain regions.

The topography of the Arcata area is bounded to the east and south by mountains, forming a basin conducive to stable development and entrapment, so that fogs are commonly 1,500 feet thick and may range to more than 3,000 feet, spilling over the mountains. Figure 5 is a rawinsonde plot showing a typical fog that occurred 12 August 1968.

During the autumn months, radiation processes can also be effective in fog formation, and produce the principal type of fog in the inland valleys to the east. As the winter regime approaches, the necessary conditions of stability are broken up by the passage of frontal storm systems.

A large industry in the Arcata region is lumbering and sawmill operations. The burning of waste wood products contaminates the atmosphere with very-small-particle smoke and haze nuclei,

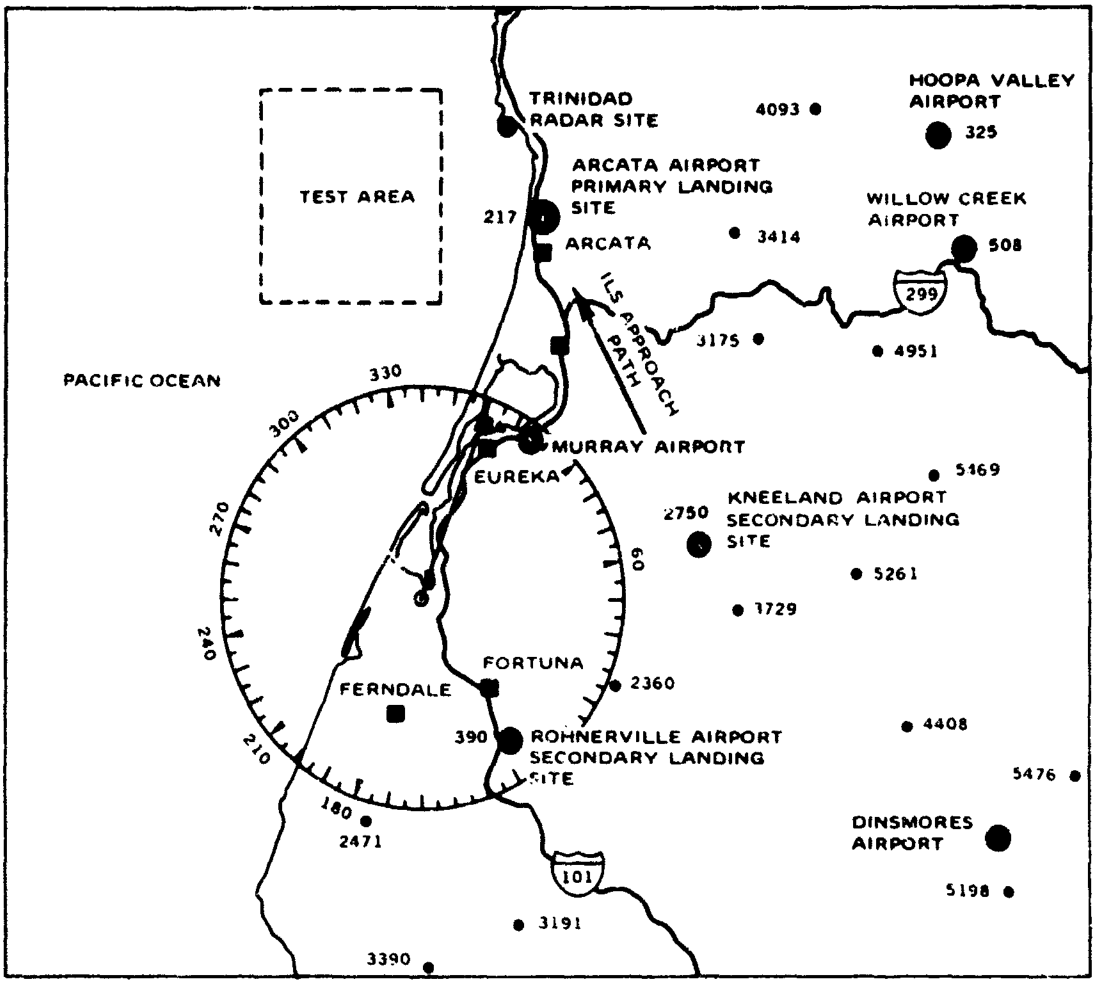


FIG. 2. Test Area.

complicating the problems of fog clearing with hygroscopic materials.

The National Bureau of Standards has issued a very interesting summary of low visibility conditions at the Arcata-Eureka airport (Ref. 5).

PLANNING

NWC has conducted, since 1957, research and development in materials and methods of weather modification. A number of pyrotechnics generating ice nuclei have been developed for modifying cold clouds and cold fogs, and also chemical smokes that theory suggests may have effects in warm clouds and fogs. Supplies of pyrotechnic seeding units of various kinds were on hand when the project began. These units were relatively untried in field experiments in warm fog. The initial phase of the project employed pyrotechnic seeding agents. During this time, capabilities to test hygroscopic powders and solutions were being developed for testing in the second phase of the work.

In exploratory work conducted in 1966 near Hollister, Calif., NWC tested an air-dispensed ammonium nitrate solution that showed some promise as a cloud dissipation agent. Ten tests were conducted using agricultural spray aircraft. Approximately 100 gallons were sprayed in a tight

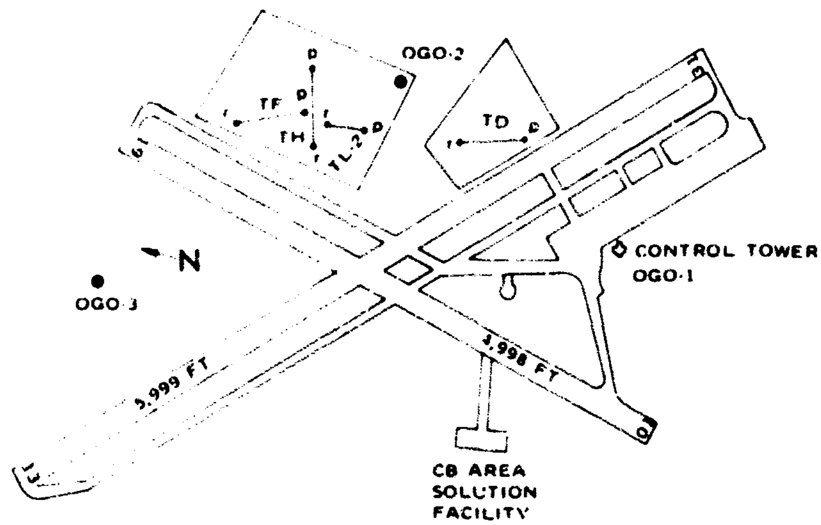


FIG. 3. Transmissometer Locations.

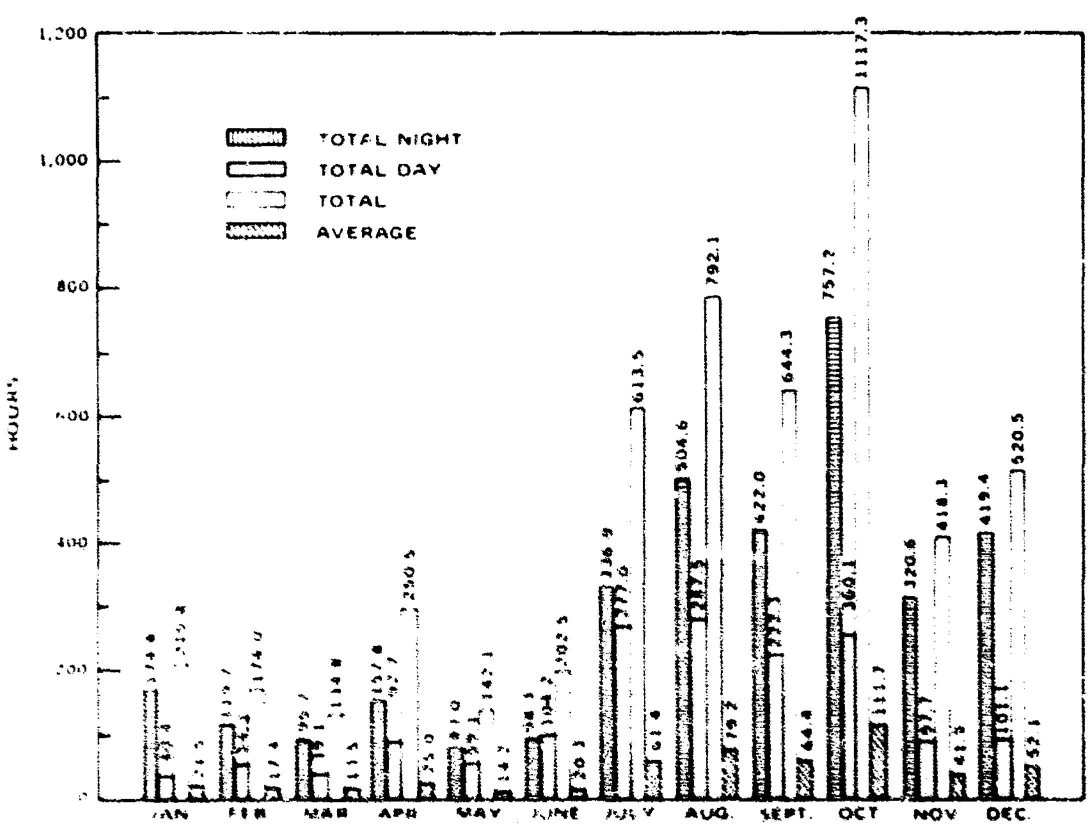


FIG. 4. Low Visibility Conditions at the Arcata-Eureka Airport by Month for 1957-1966.

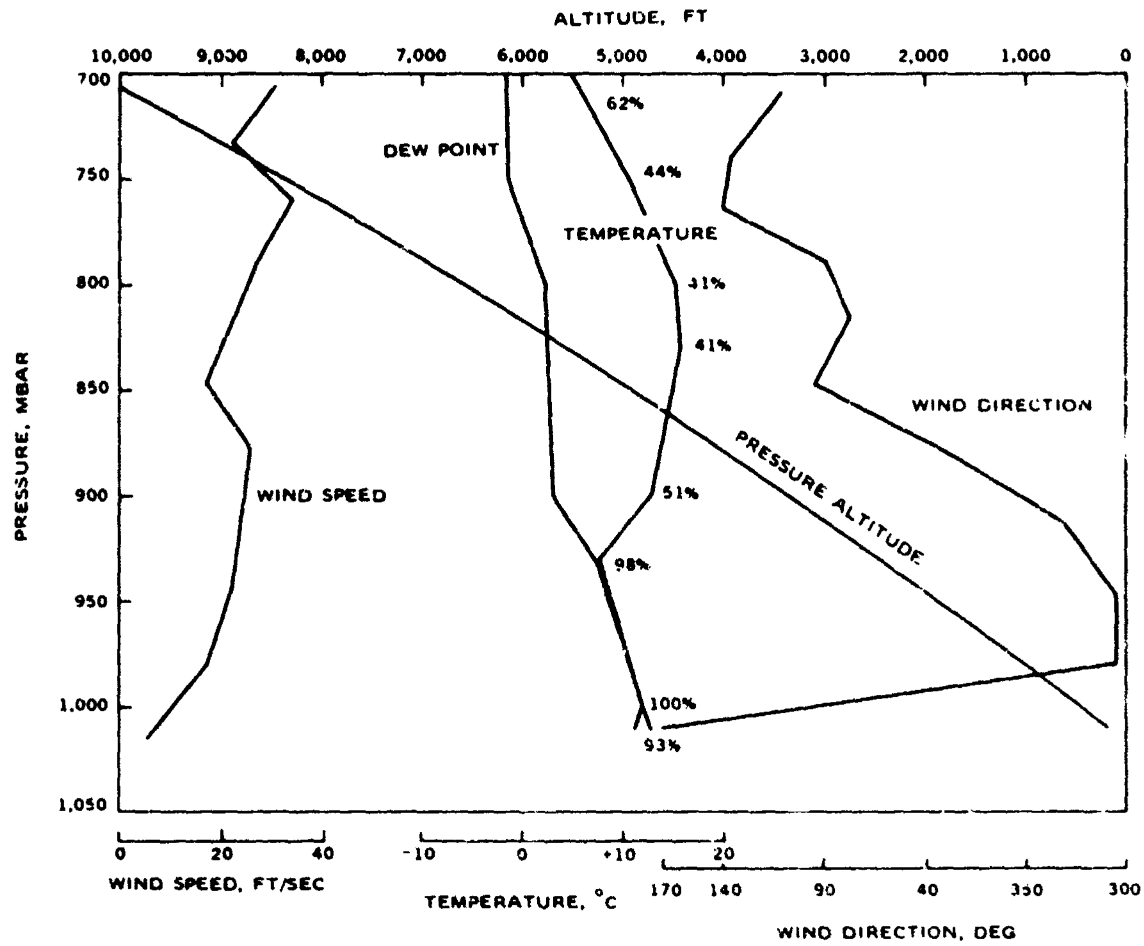


FIG. 5. Rawinsonde Plot, 12 August 1968.

turn at airspeeds of around 75 to 80 knots. Nine trials resulted in rapid clearance of stratus, producing holes big enough to fly through. Droplets of the order of 150 microns were produced, and the solution was cold.

In planning Project Foggy Cloud, NWC hosted discussions attended by personnel from the Army Atmospheric Sciences Laboratory, Cornell Aeronautical Laboratory, and the Navy Weather Research Facility. During these discussions, Cornell Aeronautical Laboratory personnel reviewed their theoretical and fog-chamber studies treating warm fog with carefully sized sodium chloride powder. Navy Weather Research Facility scientists discussed results of computer modeling of seeding warm fog and made recommendations on several types of hygroscopic powders.

It was decided to test a wide variety of seeding methods in search of a small number showing the most promise under certain weather conditions. In later projects, the number of methods will be reduced so that more evaluation can be given to each in variable weather.

In May 1969, personnel from the Cambridge Research Laboratories and Navy Weather Research Facility offered assistance in impending Foggy Cloud tests with hygroscopic materials. Statements prepared by these persons, specifying their assistance, were incorporated verbatim into the project Operational Plan,[2] which governs the testing of hygroscopic solutions and powders.

[2] Naval Weapons Center. *Foggy Cloud, OP Plan 4-65*, by Earth and Planetary Sciences Division. China Lake, Calif., NWC, June 1968.

ORGANIZATION

The project was conducted from March to mid-November 1968, in accordance with Operation Plans 2-68 and 4-68 of the Earth and Planetary Sciences Division, NWC. This group provided overall sponsorship and direction for the project, working in collaboration with the Army Atmospheric Sciences Laboratory, the Cambridge Research Laboratories, and the Navy Weather Research Facility. Seventeen other government agencies and civilian organizations contributed in some way to technical or operational aspects of the work. The principal contractor was Meteorological Operations, Inc., Hollister, Calif., which furnished men, aircraft, and other equipment.

EXPERIMENTAL TECHNIQUES

SEEDING AND DATA-GATHERING EQUIPMENT

The equipment used for project testing varied according to the work phase, but in general was as is shown in Table 1. Other devices used were field electrometers, a meteorological van for measuring physical properties of the fogs, and two large vertical-wind machines, tested briefly as ground-based seeding methods.

PROJECT AIRCRAFT

The B-25 spray aircraft is shown in Fig. 6. It has been modified by the addition of an agricultural-type spraying system for dispensing hygroscopic solutions. Wind-driven pumps feed booms under each wing. A storage tank holds 1,000 gallons, but weight limits reduce usable loads to a lesser amount, depending on solution density. In addition, during the last week of the project, two Air Force C-123s were used. These aircraft (Fig. 7) carry 1,000 gallons, so the solution capability of the three aircraft was 2,700 gallons.

A C-47 Navy aircraft served as seeder aircraft for dispensing powders. Figure 8 shows the hoppers into which sacks of powdered material were dumped, to be pumped overboard by

TABLE 1. Foggy Cloud Equipment.

Unit	Function	Special features	Type test
C-47	Seeder aircraft	2 hoppers, electric augers	Powder dispersing
Cessna light aircraft	Seeder aircraft	Hopper, gravity feed	Powder dispersing
B-25	Seeder aircraft	1,000-gal tank,[a] spray booms	Solution spraying
C-123	Seeder aircraft	1,000-gal tanks, spray booms	Solution spraying
Cessna light aircraft	Pyrotechnic seeder	Flare racks	Pyrotechnic seeding
M9 truck	Solution mixing	Tank, pump, heater	For filling spray aircraft
Ground meteorological devices	Project meteorological data	Standard	All types
Ground stations	Observations	Weather, photo, visual observations, drop slides	Over airport
Cessna light aircraft	Photo plane	T-11 aerial camera	All types
Cessna light aircraft	Cloud descriptive data	Minilab unit	All types
Cessna light aircraft	Observations	Cameras, communications	All types
Airport instruments	Routine meteorological data	Ceilometer, transmissometer	Over airport
Radar	Aircraft control, wind	Tracking and plotting board	Over sea
Motor launch	Observations and drop slides	Balloon release for winds	Over sea

[a]Lesser amounts of dense solutions were used because of takeoff weight limitations.

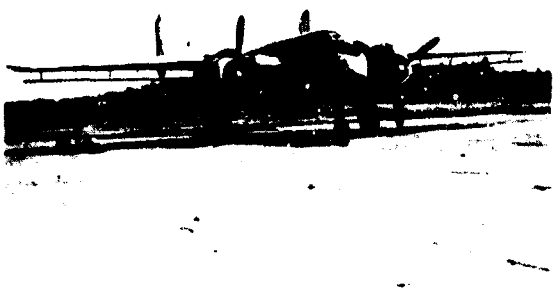


FIG. 6. B-25 Spray Aircraft.

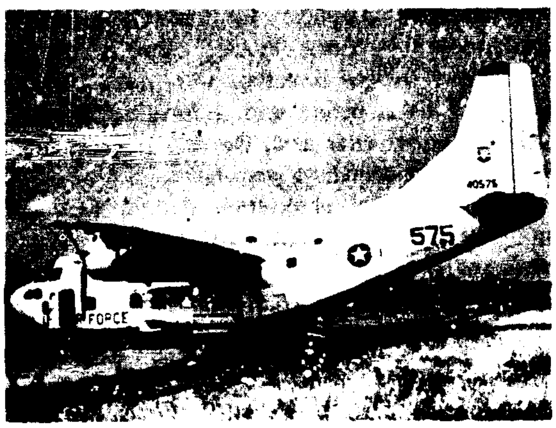


FIG. 7. C-123 Spray Aircraft.

FIG. 8. Powder-Dispensing System.

electrically driven augers. The speed of the augers was controllable according to the desired seeding rate.

Figure 9 shows a close-up of the Minilab console as it sits in the Cessna 205 aircraft. This device is connected with instruments in a pod under the wing. Exposed to the airstream, these instruments sense pressure altitude, temperature, dew point, and liquid water content. Values of these parameters are compared before and after seeding and are used to quantify the changes produced by seeding. The console yields a continuous oscillographic record. An operator can punch in digital data coded to record other information, such as the position of the aircraft with respect to the seeded cloud. A typical record from the Minilab is shown as Fig. 10.

A Cessna 206 aircraft was used for aerial photography at altitudes about 12,000 feet above the test area to show the effects of seeding in the fog tops and whether a hole appears as the result of seeding. Figure 11 shows an aerial photograph

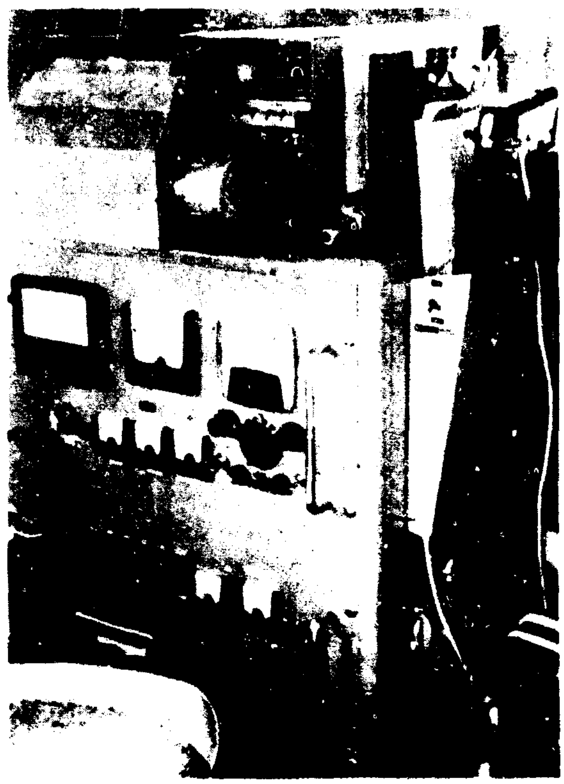


FIG. 9. Minilab Console.

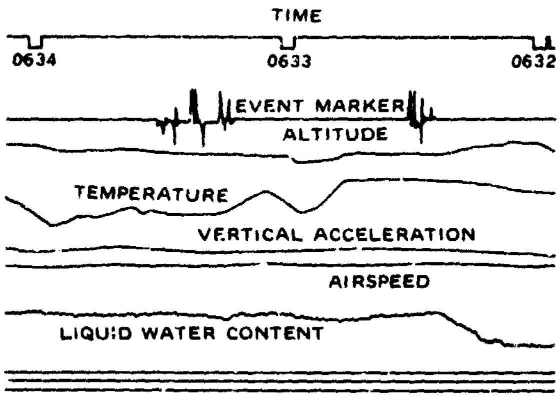


FIG. 10. Section of Typical Minilab Record.

FIG. 11. Distrail Generated During Orbital Seeding.

of the distrails (dissipation trails) generated during an orbital seeding test, and illustrates the quality of photographs used for stereophotogrammetric measurements of the domes produced by the pyrotechnics.

A Cessna 210 aircraft was used as a control aircraft. The project director could monitor and direct the operations from a vantage point above the area as the other aircraft made their passes. Photographs were taken with a hand-held Leica camera, and 16-mm photographs were made from this aircraft.

GROUND INSTRUMENTATION

The Army Atmospheric Sciences Laboratory supplied a radar system (Fig. 12) capable of tracking two targets for plotting and positioning aircraft and the boat observation station. The radar units were located at Trinidad Head on Coast Guard property. From there, an uncluttered view of the area allowed all traffic at sea and in the air to be monitored. The winds in the target area were also computed from tracking a reflector on a released balloon, or by tracking an aluminum foil target dropped from the Minilab aircraft. The corrections for positioning the seeder aircraft with respect to the target area could then be made.

An Army team with ground meteorological devices was supplied for project weather information by Yuma Proving Ground, Yuma, Ariz. Three to four soundings were made on test days, at 2 hours before seed, 1 hour before seed, and 30 minutes after seed. On days of more than one test, more soundings were taken.

Outlying ground observation stations were set up for taking weather observations, visual observations, and photography at various locations at the airport, at the control tower, and in the project boat, a Boston whaler-type craft.

AIRBORNE SEEDING METHODS

Because of the nature of the materials used, airborne test operations were divided into two types: over-sea seeding with the more corrosive types of powders and solutions, and over-the-airport seeding with pyrotechnics and less corrosive solutions and powders. The selection of the test site naturally depended on weather occurrence also.

Over-Sea Tests

Use of corrosive materials, such as calcium chloride and sodium chloride powders, was with a few exceptions restricted to over-sea testing. In such tests, the seeder and Minilab aircraft were controlled by radar. The area for testing was picked, based on either the observation boat's

FIG. 12. Tracking and Plotting Radars.

position or Minilab aircraft scouting observations. Next, a plot of the site wind vector was obtained as a function of altitude. For this purpose, either a balloon with a corner reflector was released from the boat, or a roll of aluminum foil was dropped from the Minilab aircraft. The foil method proved more convenient and economical, and could be used when the boat was not launched.

The Minilab aircraft then made a series of data passes to get the temperature, dew point, and liquid water content (LWC) profiles at altitudes in the fog layer. Generally a sounding pass was made by descending through the layer until the cloud base or a minimum altitude of 200 feet above the surface was reached. This was done on vectors given by the radar controller.

The seeder aircraft then made its passes, flying an orbital, racetrack, or other pattern as directed by the radar controller, in accordance with the test plan. In some cases where repeated application to the same track was desired, the pilot of the seeder aircraft was directed by the pilot of the aerial photography aircraft, who had the best view of the seeded track. Most seeding was conducted with the aircraft skimming the cloud tops. In such cases the persistence of the seeder-aircraft trail made the visual control method superior even to radar positioning for overlaying repeated treatments.

After seeding, the seeder craft departed and the Minilab aircraft made a series of data passes with radar control in or below the seeded track. Before-and-after photographs and visual observations were made continuously from the orbiting observation aircraft, and aerial photographs were taken by the high-altitude photo aircraft. The altitudes of the photo aircraft ranged from 6,000 to 12,000 feet MSL, depending on intervening cloud layers and on whether cloud details or wide-area surveillance was desired. The boat team was responsible for visual and photographic observations, temperature and dew point measurements, and drop slide exposures. Many times, rough seas prevented the deployment of the boat. In these cases, cloud-based conditions were determined by a Minilab aircraft sounding pass.

Over-Land Tests

Whenever possible, tests over land were made at the Arcata-Eureka airport in order to take full advantage of the observation stations and the instrument network, as well as the instrument landing system and marker beacons.

At the start of the test, the Minilab aircraft made its preseed passes to the approach end of the runway and flew at altitudes outlined in the test plan. The seeder aircraft then seeded in the desired pattern at the north end of the runway, or along the length of the runway. Next, the Minilab aircraft flew through the seeded volume for the desired altitudes and number of passes for postseed observations. Meanwhile, observation continued from the observation aircraft and photo aircraft above. The number of Minilab passes and the duration of on-top observation depended on the extent of the reaction to seeding. Visual and instrumental changes were observed from the ground stations, including the official airport weather observation function.

In some cases, when suitable test weather was not occurring at the airport, the team was deployed to other over-land sites. These deployments were based on all available weather information gathered by project personnel, often including weather scout reports from project flights.

It was recognized that the use of remote test sites would often yield an incomplete data package. Tests in valleys would be without surface observers. Rugged terrain might preclude low-level flights to gather in-cloud data. Even so, a test for gross effects could be run and observed from above in such cases. A partly documented test was judged more profitable than no test at all, even though the results were sometimes inconclusive.

GROUND-BASED TESTS

Ground-based testing was conducted only within the confines of the Arcata-Eureka airport, and only during dense fogs. The latter restriction was imposed to make noticeable small-scale effects. In selecting sites for placing the seeding equipment, consideration was given to aiming the effects toward downwind observation points, instruments, and convenient paths of flight for the Minilab aircraft. Because of the nature of the seeding equipment, site selection was limited to areas served by roads. No mobile seeding was done.

Agents tested were several types of pyrotechnic units as well as the 9:1 ammonium nitrate/urea solution. The pyrotechnic units were placed on the ground and ignited. No platform or other equipment was required other than to transport the units to selected locations.

For solution testing, two special vertical-wind machines were used in separate tests. The first of these was called the Fog Fan (Fig. 13), a device built by Meteorological Research, Inc., for Cambridge Research Laboratories. The Fog Fan was made available to us through coordination with Air Weather Service.

The second vertical-wind machine available briefly at Arcata was Food Machinery Corporation's "Fog Sweep." This experimental unit was used in some tests in the Sacramento work.[3] Fog Sweep consists of a towable unit with a storage tank, blower, and a long, plasticized, flexible, cylindrical air duct. A manifold with several nozzles at the exit end of this tube allowed the use of hygroscopic spray (Fig. 14).

One test was run under fog conditions; however, mechanical problems arose in the blower system after only a few minutes and 10 gallons of spraying, and the test was abandoned. This was not a fair test of the device, nor would similar mechanical failures be frequent. The trial is reported to explain why the lower limit on the range of ammonium nitrate/urea solution used in the test series was an inadequate 10 gallons.

In all ground-based tests, the density of the observer network was increased near the test site.

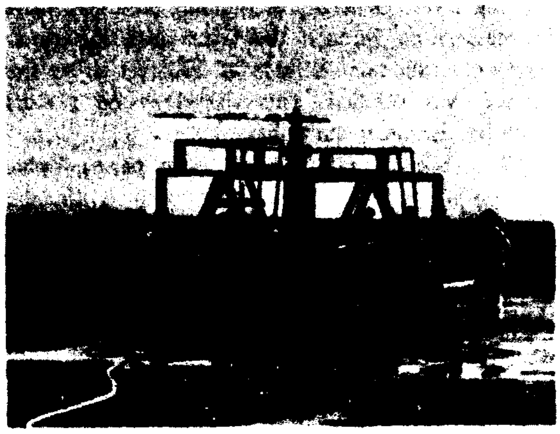


FIG. 13. Fog Fan Vertical Seeding Machine.

[3] Naval Weapons Center. *Observation and Verification* . . . , *loc. cit.*

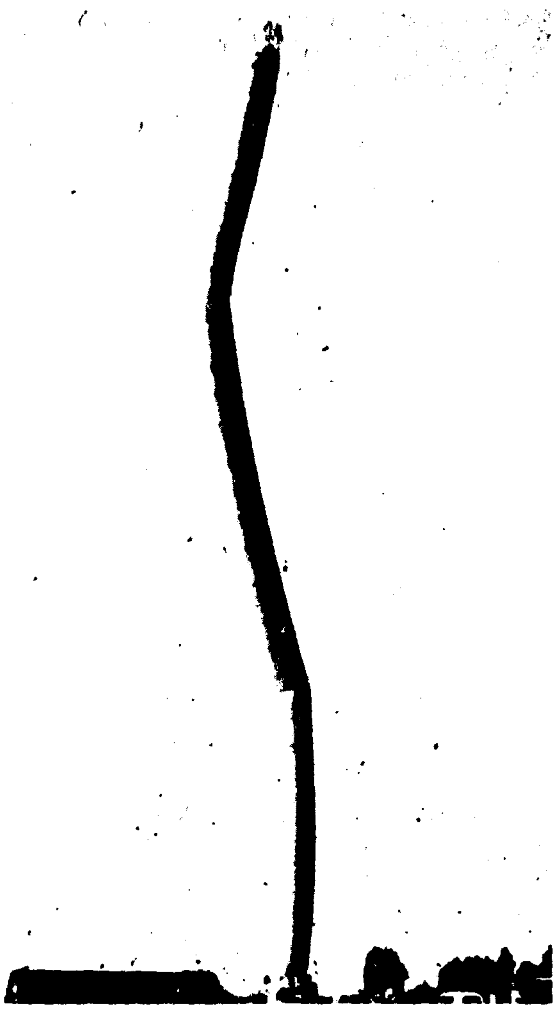


FIG. 14. Fog Sweep Vertical Seeding Machine.

The most valuable observations of effects were those taken by observers near the pyrotechnic generators. This was particularly true when only one seeding site was used.

SCHEDULING OF TESTS

Because of the screening nature of much of the Foggy Cloud test series, individual tests were modified as rapidly as information from previous tests could be incorporated. The progression of tests was patterned after some 30 formal test plans written on site. A certain amount of continual redirection was necessitated by the fact that some personnel, equipment, and materials were available for only a limited portion of the total project time. For example, two C-123s augmented the total solution capacity to promising levels, but were available less than 5% of the project period. Similarly, when limited supplies of certain chemicals had been exhausted in tests, the resupply delays did not allow delivery in time for additional testing. For these and other reasons, the kinds of tests run from day to day varied.

Because of these factors, the analysis team supplied a variety of test plans from which one or more seeding or supporting tests tailored to any kind of weather (fog or stratus at sea or at the airport) could be selected.

Depending on weather, a given day might be spent in testing or in supporting activities such as maintenance and data reduction.

When seeding was possible, a mission briefing was held during which operational assignments were reviewed in accordance with the test plan. All seeding tests were conducted with enough daylight to allow photography. On some days the fog or stratus was persistent and widespread enough to allow a second independent test. At other times aircraft had to land at alternate airports, which temporarily disrupted further seeding for that day. As soon as possible after a test, and most often the same day, all test participants met to discuss results, turn in data, and receive assignments for further work.

CHARACTERISTICS OF MATERIALS

PYROTECHNICS

The pyrotechnic materials used were of two general types: (1) airborne fusee units, which are electrically fired and burned in place in a horizontal rack mounted behind the aircraft wing; and (2) large cylindrical units, which are burned on the ground. Seeding materials from airborne units can be dispensed at any desired level within the cloud deck. Wider dispersion results from the flight path and turbulent wake of the seeding aircraft. The ground-based units depend on heating, natural convection, and turbulence to produce the mixing necessary for material dispersal. Thus the dispersion may vary widely because of wind conditions.

The characteristics of the various units are given in Table 2.

The particle sizes of the combustion smokes depend on temperature and composition. Sizes range downward from about 0.5 micron to perhaps 0.01 micron, the larger particles being oxides. The size range is thus about two orders of magnitude smaller than that of the dry powders used in other tests.

Burning times for the airborne fusees can be tailored to the application, and are typically 2 minutes or so. The large cylinders burn out in 5 or 6 minutes.

The 2AL2, EW20, and LW83 are units that were developed and used in cold-cloud seeding. These were tried because they were on hand at the beginning of the project, certain of the combustion products are mildly hygroscopic, and the smokes are electrically charged. It was known that these units could not work in warm clouds by the same mechanisms that make them successful for cold-cloud work. Nevertheless, it was thought that it would be worthwhile to test them for unexpected results in warm-cloud field tests.

The other units with the exception of Briteye were designed as hygroscopic nuclei generators. Briteye is primarily a light-giving flare whose smoke is partially hygroscopic. It was recognized from other work that large amounts of material would be required; therefore the ground units were made from one to two orders of magnitude larger than the airborne fusees.

The Salty Dog unit was originally designed for joint experiments with the University of Hawaii. This unit was successfully parachute-dropped off the Florida coast during experiments in the Cloud Puff I project. In moist air, an intense, bluish-white hygroscopic smoke forms that persists for 20 minutes (Fig. 15).

The Salty Frog units were designed to be more intensely hygroscopic than the Salty Dogs. The percentages of lithium compounds were increased in order to start water vapor absorption at lower concentrations (i.e., about 30% relative humidity). The amount of magnesium was increased to give higher temperatures and thus smaller resultant particle sizes. The control of particle size is an important factor in the results obtainable from seeding with hygroscopic pyrotechnics. Whereas the larger particles encourage the formation of water

TABLE 2. Characteristics of Pyrotechnic Units.

Designation	Composition, wt. %	Type	Gross wt., lb
2AL2	$AgIO_3$, 28%; Al, 11%; KNO_3 44%; Mg, 11%; binder, 6%	Fusee	1
EW20	$AgIO_3$, 28%; Al, 15%; Mg, 7%; KNO_3, 44%; binder, 6%	Fusee	1
LW83	$AgIO_3$, 78%; Al, 12%; Mg, 4%; binder, 6%	Fusee	1.1
WF8	Hexachlorobenzene, 75%; Mg, 20%; binder, 5%	Fusee	1
Salty Dog (558)	NaCl, 17%; $KClO_4$, 61%; Li_2CO_3, 1%; Mg, 3%; binder, 18%	Cylinder	185
Salty Frog I (CY-85)	NaCl, 10%; $KClO_4$, 65%; Li_2CO_3, 2%; Mg, 5%; binder, 18%	Cylinder	37
Salty Frog II (CY-91)	NaCl, 30%; $KClO_4$, 24%; NH_4ClO_4, 17%; Li_2CO_3, 5%; Mg, 6%; binder, 18%	Cylinder	34
Briteye	Mg, 61.5%; $NaNO_3$, 33.9%; other, 4.6%	Cylinder	82

FIG. 15. Salty Dog Unit Dropped by Parachute.

FIG. 16. Ground-Based Pyrotechnic Unit.

droplets and subsequent precipitation with clearing of the air, the smaller particles tend to be so much more numerous that the droplets formed can grow only slightly. The competition for the remaining water vapor in the air causes the particles to stop growth and remain as a very intense stable fog. It is thus theoretically possible to clear a fog through the use of hygroscopic pyrotechnics, or to cause the fog to intensify, stabilize, and persist, depending on proper weather conditions and design of the chemical composition and particle size of the pyrotechnic unit (Fig. 16).

The heat released from burning the larger units was of interest, because it would possibly cause convective lifting. It was unknown, for instance, how much clearing was caused by hygroscopic effects and how much was due to heat alone. The heat of combustion is typically 2×10^3 calories per gram of pyrotechnic. A study was made of the amount of rise to expect from combustion only (Ref. 6). This study is described in Appendix A.

SOLUTIONS

Table 3 lists the seven solutions tested during the course of Project Foggy Cloud. Commerical-grade chemicals, guaranteed to be at least 90% pure, were used in all solution preparation.

Mixing and Handling

Solutions were prepared by dissolving chemicals in river water. This was accomplished in an Army M9 power-driven decontamination apparatus

TABLE 3. Solutions Tested.

Solution	Water content, wt. %	No. of tests	Amount of material, gal
Ammonium nitrate[a]	40	7	400-800
Ammonium nitrate/urea/ water (9:1)	10[b]	12	10-2,700
Calcium chloride[a]	60	1	650
Sodium chloride[a]	74	2	750
Urea[a]	55	3	800
Water, river	100	4	400-600
Water, sea	96.5	1	400

[a] Nearly saturated at 10°C.
[b] 20% for one of the 12 tests.

(PDDA), which is a 450-gallon tank on a 2 1/2-ton truck chassis. The PDDA has pumping, heating, and mixing capabilities. Mixing a 450-gallon batch typically required two or three men and 2 to 4 hours.

Solutions were stored in either the PDDA or in a 1,500-gallon cylindrical steel tank. Besides facilitating operations, storage permitted settling of undissolved solids, principally impurities in the commercial-grade chemicals. In order to prevent precipitation of the dissolved chemical it was necessary to maintain some of the solutions at temperatures above ambient. In the 1,500-gallon tank this was accomplished with a 3,000-watt electrical resistance heater. Aircraft loading occurred just prior to testing in order to minimize settling out of solids in the aircraft system.

During the last week of testing, when solution requirements were unusually high, a solution meeting specifications was mixed by Chevron Chemical Company and delivered in insulated tank trucks with heating and pumping capabilities.

Development of Multicomponent Solutions

At the request of the Atmospheric Physics Division, White Sands Missile Range, it was agreed to investigate the fog-dispersing potential of an unsaturated solution of ammonium sulfate and urea. After reviewing the properties of the proposed solution with the proponents of this solution, it was decided that a solution of ammonium nitrate/urea be tested instead. A series of formulations was prepared, the intent being to minimize the partial pressure of water vapor in equilibrium with the solution and thereby enhance the driving force for the transfer of water from the atmosphere to the solution. Initial work involved urea, ammonium nitrate or ammonium sulfate, and water. A solution of 4 parts by weight of ammonium nitrate to 3 parts urea was found to be particularly promising, and solids-to-water weight ratios as high as 14:1 were achieved for the chemically pure solution in the vicinity of 10 to 15°C.

Fog Chamber Studies

Laboratory solutions were qualitatively tested on artificial fogs generated by a small orchard sprayer and confined within a 23-cubic-meter room that was adapted from existing airport facilities. Typically, 10 to 15 milliliters of a 9:1 solution, such as the above, would dramatically thin a heavy artificial fog in about 15 seconds.

More extensive and more quantitative tests of project seeding materials were conducted in the Cornell Aeronautical Laboratory cloud chamber. Details are given in Appendix B.

Other Laboratory Studies

Tests of 9:1 Solution. NWC made extensive and detailed laboratory studies of the solubility, pH density, viscosity, and vapor pressure of the system ammonium nitrate/urea/water. In addition, hygroscopicity investigations indicated that at room temperature the 9:1 solution absorbed from a saturated atmosphere about three times as much ambient water vapor in 1 hour as did an equal volume of saturated sodium chloride solution (Appendix C).

TABLE 4. Powders Tested.

Powder	Source	Trade name	No. of tests	Size range, μ wt. %	Amount of material, lb
Calcium chloride	Deepwater Chemical	Special	9	1-40	400-1,500
Sodium chloride	Leslie Salt Co.	Micro-Vacuum Powder	1	63%<37 96%<105	800
Sodium chloride	Meteorological Research, Inc.	Special	1	46%<37 96%<105	2,000
Sodium chloride	Morton Salt Co.	Extra Fine 200	2	5-67	2,025-2,900
Sodium chloride	Morton Salt Co.	V.F. 50/50 Flour Prepared Salt	4	<1 to >250	2,000-3,000
Urea	W. R. Grace & Co.	Special	1	20-40	1,500

Corrosion Tests. The corrosive tendency of the 9:1 solutions was gauged on site, by subjecting copper pennies or aluminum foil pieces to various solution environments for prolonged periods of time. The copper discolored, but the aluminum appeared unchanged. An attempt was made to reduce even further the rather slight corrosiveness of 9:1 solution by substituting glycerin or isopropanol for much of the water. In this respect, the former appeared much more satisfactory. No seeding tests were conducted with these nonaqueous solutions.

POWDERS

The six powders tested are listed in Table 4.

Solid chemicals were stored either in an explosives magazine or under an openside shed near the solution storage tank.

Prior to testing, the seeding chemical was removed from its commercial wrapping (often heavy multiple-layer paper) and placed in small, easily manageable sacks of less sturdy material. The primary purpose of this rebagging was to substitute confining material that would more easily pass through the airborne solids-dispensing system, which consisted of a hopper and a discharge tube fitted with a motor-driven screw. The use of these lighter materials permitted sacked chemicals to be introduced directly into the hopper without removal of the sack. This practice made possible not only a safer, cleaner, and pleasanter operation, but one sufficiently fast to allow continuous, high-rate discharge.

Two types of commercially available, plastic utility bags were tried. The thinner proved less satisfactory because of its tendency to stretch and wrap around the screw of the dispenser rather than to shear. The best bag material tested was ordinary grocery bag, in either double or single thickness. No completely satisfactory material was found, as all tended to accumulate in the discharge tube, thus causing diminished and erratic flow and eventual stoppage.

All rebagging was done as quickly as possible, just prior to testing, in order to minimize clumping caused by the absorption of atmospheric water by the hygroscopic chemicals.

The size distribution of several powders was determined at NWC via sieve analysis or microscopic inspection. Table 5 illustrates an analysis of one of the powders tested.

TABLE 5. Sieve Analysis of Morton Salt Co. Salt Sample Labeled Hutchinson Plant, Extra Fine 200.[a]

Particle size fractions, wt. %	Particle size range, μ	Mean particle size, μ
0.64	>250	...
0.16	250-177	214
0.15	177-149	163
1.09	149-105	127
4.63	105-74	90
3.96	74-63	68
10.79	63-44	53
11.78	44-37	40
66.45	<37	...
99.64		

[a] Sample received 23 September 1968

EXPERIMENTAL DATA

During Project Foggy Cloud, a wide range of data was collected and examined to judge the nature and effectiveness of seeding methods, the characteristics of materials, and the properties of the treated and untreated environment. These data, discussed below, may be classified as follows: routine meteorological, project meteorological, cloud descriptive, technique descriptive, photographic and visual, and special. The information chosen to be gathered during any specific test was preplanned; the choices depended on the nature and location of the test as well as the availability of men and functioning equipment.

The routine meteorological data were those that other groups normally gather at Arcata independently. These included the local airport weather observations, augmented by a network of special transmissometers. Additional weather forecast and observational data were obtained from facilities routinely operating in the airport tower, or from various military and civilian weather offices.

Project meteorological observations were taken by project members at specially designated sites in order to increase the density of the observing network. Up to four outlying ground observation stations could be manned on the airport to collect data on winds, temperature, dew point, precipitation, light intensity, and visual effects of seeding. The precipitation data included time-lapsed replications of settling fog droplets collected on gelatin-coated microscope slides. Special rawinsonde ascents gave vertical soundings of temperature, dew point, and wind at the airport.

The cloud-descriptive data were taken using the airborne Minilab sensing-recording system. Measurements of cloud liquid water content, air temperature, and dew point, as functions of time and altitude, were obtained in essentially real time. Using a digital code, the operator punched in further information on position (e.g., over middle marker), flight condition (e.g., in cloud), and event sequence (e.g., first postseed run).

Technique-descriptive information was compiled to portray the seeding method, amount and characteristics of the seeding agent, times and patterns of seeding, etc. For this purpose a number of log sheets were completed routinely, and notes were taken in debriefing sessions after seeding missions. For offshore tests, the position of key aircraft or observing vehicles (including the motor launch) was monitored by radar. The end product was a graph showing position versus time. The radar also obtained wind-drift information and the related probable movement of seeding materials released into a fog at sea.

Photographic and visual observations were always made, even when test conditions or goals obviated the acquisition of other kinds of data. Pictures included 35-mm color stills and time-lapse series, 16-mm movies, and aerial black-and-white stills in a 9- by 9-inch format. Some of the latter were compiled into mosaics or used in stereo pairs for photogrammetric measurements of seeding effects. All observers were asked to submit written narrative comments on what they saw, and comparative discussions were noted during debriefings.

Into the *category of special studies* fell those data that were compiled for only a relatively few tests, or for which the measuring equipment is still in a developmental state. Parameters measured in these studies included electric field and space charge, drop-size distribution, in-cloud backscattered radiation, cloud liquid water content near the surface, and in-cloud air conductivity. In most cases, such data were taken as part of side studies in instrument development or fog characteristics rather than as part of the data package compiled to describe routine seeding tests.

Information on the drop-size distribution in the cloud before and after seeding was not routinely available. This lack stemmed mostly from the difficulties in maintaining, operating, and reducing data from available airborne devices used to measure this parameter. Research has been conducted to study ways of measuring drop-size distributions in clouds without requiring elaborate data reduction (Ref. 7). Such a system would be a valuable adjunct in many weather-modification projects.

DATA REDUCTION AND HANDLING

Whereas many kinds of data came in a reduced form, others, such as Minilab information and droplet slide replications, required many man-hours of hand reduction. Teams of project members or specially hired assistants accomplished these chores on a routine basis, on site at the project office.

The recorder charts from the Minilab rolls were regraphed by tracing and decoding digital inputs. These graphs are more legible, more permanent, and more selective of particularly significant data runs than the original charts. This step was also necessary to relate the various pen deflections to calibrated values of parameters of interest.

Droplet replications on gelatin-coated slides were taken by the ground stations and examined under a scaled microscope. Counts were made of the droplets in the different size ranges, and then the counts were plotted to show the drop-size distribution. In this way, it was possible to compare the drop sizes of the fogs to detect whether there were atypical conditions occurring, and to compare the before-and-after seeding drop sizes for effects of droplet coalescence, or other changes.

These measurements are given in the drop diameter as scaled from the microscope slides, without a factor to relate to true drop diameter. There are various factors given in the literature, somewhere between unity and 2, depending on the replication technique and method of reading the annular-shaped crater. However, the relative changes in drop sizes are of more interest than are absolute sizes.

The only other kind of data that took significant time to reduce was photography. Photographic processing was arranged commercially, and prints could be obtained within a few days after delivering the film.

ANALYSIS

Except for special studies, the majority of Foggy Cloud test data was compiled and analyzed on site. This was done so that the results of day-to-day activities could be used to plan impending tests in the series. It often happened that even a cursory analysis of the entire data package uncovered definite evidence of seeding effects that were not immediately noticed during the tests. Furthermore, about one-third of the project tests were not seeding tests *per se*, but were run to study some aspect of the seeding technique or the environment. Such supporting tests were especially valuable in directing later experiments along the most potentially profitable lines.

A data folder was compiled for each test and was used to store pertinent data as they became available in reduced form. Heavy emphasis was placed on analyzing each test as an individual case study. Because a wide variety of seeding techniques were tried, and test goals also varied somewhat from day to day, some of the test results are not comparable. Nevertheless, when time and rationale permitted, case-to-case comparisons were also conducted on site.

Again, depending on the test goals and location, the phenomena we were examining most closely might one day be subtle changes in the microphysical characteristics of the fog, and the next day be the presence or absence of noticeable changes in the cloud structure, surface visibility, or other gross effects. The absence of large-scale effects would be clear evidence that the particular seeding technique was not operationally usable. The judgment that no beneficial changes resulted from such a seeding was, however, one that could not be made until all data were considered.

PROJECT FINDINGS

PYROTECHNICS

Airborne

A total of 11 seeding tests were run using airborne pyrotechnics 2AL2, EW20, LW83, and WF8 fusee units. The number of units used in a single test ranged from 10 to 37. The variation in this number was attributable partly to experimental plan and partly to electrical ignition problems in some tests. The overall scheme was to test each type of unit until two tests gave similar conclusive results. Seeding techniques included various flight patterns and seeding levels, both at the top and within the cloud or fog layer.

It was recognized beforehand that the smoke particles from these airborne units were probably too small to serve as hygroscopic nuclei on which to grow droplets of significant fall velocity. Fog-clearing effects, if any, would have to be produced by some additional mechanism, such as effects from the electrical charge that the smoke particles possess. A field demonstration that such pyrotechnic units in the numbers used are not effective in clearing warm-cloud forms was considered a worthwhile finding.

These tests had the additional benefit of giving needed practice in performing airborne test seeding missions as an integrated team. In this sense, they supplanted the "dry runs" normally required in field projects of this type, enabling actual tests to be performed while techniques used in later work were perfected.

Ground-Based

There were several reasons for testing ground-based pyrotechnic units. First and foremost, a ground-based technique, if successful, is for many field applications preferable to one requiring aircraft. Second, the units tested were readily available. Third, unlike the airborne pyrotechnic units, the ground-based units were designed specifically for warm-cloud work and had proven in limited field testing to emit intensely hygroscopic smoke. Finally, the size of the ground-based pyrotechnics allowed us to concentrate larger amounts (estimated in one test to be as much as 10^5 particles per cubic centimeter) of the seeding agent in a relatively small volume of fog, compared to the airborne tests.

In summary, the results of a total of 13 tests with Salty Dog, Salty Frog I, Salty Frog II, and Briteye units showed definite evidence of seeding effects, but these effects were not consistently in the direction of clearing the fog. Effects attributed to seeding and in the direction of improvement included drizzle-like precipitation in the fog downwind of the ignited units and small-scale increases in vertical and/or horizontal visibility. Clearing effects could not be reliably reproduced or augmented in tests with more material. At other times, test results ranged from no apparent effect to the actual enhancement of dense fog and worsening of visibility.

One of the more interesting results of seeding with the ground-based pyrotechnics was the formation of a dome of fog extending typically 50 to 100 feet above the natural top of the fog layer, over or near the location of the seeding unit (Fig. 17). Such domes were very roughly hemispheres, with a lateral dimension of 1/4 to 1/2 mile. Domes were observed frequently, but not always, with the Salty Dog and Salty Frog I and II units, but not with the Briteyes.

Attempts were made to investigate the relative contribution of heat of combustion and heat of condensation (Ref. 6). This was done by computing the height the plume should reach if it was borne aloft by convective action solely related to the heat of combustion (see Appendix A). Any excess of plume rise, as observed from the dome

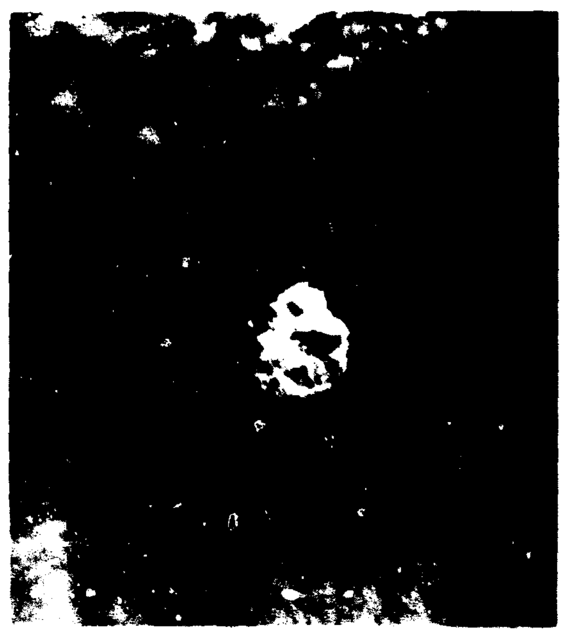


FIG. 17. Dome Produced at Fog Top by Pyrotechnic Burn on the Ground.

in a real experiment, could then be attributed to heating by condensation if the height-predictive equation was accurate. Our efforts along these lines were somewhat frustrating because the atmospheric conditions required to validate the equation were often not met in the environment of the seeding tests. Even so, assuming no heat of condensation, the equation predicted the actual heights obtained in several tests within 10% or so. It should be pointed out that one could make an equally successful plume-height prediction by adding 50 to 100 feet to the observed top of the fog layer.

However, the lifting at the top of the fog did not seem to be routinely accompanied by a corresponding lifting and improvement in the base of the fog.

Test techniques included the simultaneous ignition of spaced clusters of units, or of single units, and the sequential firing of units in one location. Numbers used per test ranged from 3 to 12 to provide roughly comparable masses in each test. In each test but one, the units were ignited in dense fog. In that one test, the fog lifted slightly as final preparations were being made. The test was run anyway, without beneficial changes in the weather following this test. A wet artificial cloud formed.

The burning characteristics of the Salty Dog, Salty Frog I, and the Briteye pyrotechnics were excellent.

Although some of the tests with these ground-based pyrotechnics gave promising results, there were enough inconclusive results in additional tests to cause abandonment of further pyrotechnic testing in favor of solutions and powders during the latter part of the project. The ability of these units, especially the Salty Dog, to form wet clouds in clear moist air is a project finding worthy of additional investigation.

SOLUTIONS AND POWDERS

Airborne Tests

Tables 3 and 4 show 18 tests with powders and 30 with sprays. All the powder tests were airborne, as were 29 of the 30 spray tests. All powder and most spray testing was performed in either warm stratus or warm fog; 2 of the 29 airborne spray tests were run using small warm cumulus clouds as targets for seeding. Thus 45 airborne tests in all were run in fog or stratus with powders or solutions.

The two cumulus tests employed 9:1 ammonium nitrate/urea solution. The first took place spontaneously when it was necessary to shed about 150 to 200 gallons of the solution to reduce the aircraft landing weight after a mission. The material was sprayed into a warm cumulus, which rapidly dissipated. The second cumulus test was planned based on the above results. A full load of solution was dumped in four doses into the top of a warm cumulus, which also dissipated after developing turbulence and subcloud precipitation. This work is being continued in other NWC projects.[4,5]

Table 6 summarizes the results of airborne seeding tests conducted in warm stratus or fog. The number of tests with each material is shown arranged as to number of tests designed to produce only minor effects and those intended to yield large, operationally useful effects. Minor-scale tests were tests designed in coordination with Cambridge Research Laboratories, to help them calibrate a computer model. In these cases, the amounts of material, flight paths, etc., were not selected to produce operationally significant clearings.

The effectiveness index was determined subjectively according to the following scheme: All airborne tests reported under large effects in Table 6 were examined individually. A few that were not observed sufficiently well for judgment were screened out as inconclusive. The remainder were separately assigned a numerical rating of zero, 1, 2, or 3. A zero rating was given those tests where no evidence of modification was found. A rating of 1 was used for evidence of small modification, including wide seeding trails, small changes of liquid water content, and thinning or bright spots forming in the cloud. The value 2 was assigned if

[4] Naval Weapons Center. *Project Gulf "Q"*. *OP Plan 1-69*, by Earth and Planetary Sciences Division. China Lake, Calif., NWC, May 1969.

[5] Naval Weapons Center. *Project Foggy Cloud II*. *OP Plan 2-69*, by Earth and Planetary Sciences Division. China Lake, Calif., NWC, June 1969.

TABLE 6. Airborne Test Results With Hygroscopic Sprays and Powders in Warm Fog or Stratus Clouds.

Material	Total tests by type		Av. effectiveness index (no. of tests)
	Minor effects	Large effects	
Ammonium nitrate solution	0	7	1.6 (5)
Ammonium nitrate/urea/water (9:1 solution)	0	9	2.3 (7)
Calcium chloride solution	0	1	1 (1)
Sodium chloride solution	1	1	1 (1)
Urea solution	0	3	1.5 (2)
Water, river	4	0	...
Water, sea	0	1	0 (1)
Calcium chloride	1	8	1.5 (8)
Leslie MVP salt	0	1	2 (1)
Meteorological Research salt	0	1	2 (1)
Morton extra fine 200 salt	0	2	0.5 (2)
Morton V.F. 50/50 salt	0	4	1.0 (4)
Grace urea	0	1	2.0 (1)

effects included small holes, deep troughs, sharp LWC changes, large precipitation droplets, or slight improvements in ceiling and visibility. The highest rating of 3 was reserved for those tests in which were achieved operationally useful results: large holes, significant visibility and ceiling improvements, etc. The ratings for each kind of material were then averaged over the number of conclusive tests intended to produce large-scale effects.

The rating system, though somewhat arbitrary, is intended to be based on an ordinal scale, zero to 3, in which equal intervals represent equal degrees of seeding result. Accepting this rationale, the computation of an average is justified statistically, even though the rating of an individual test was somewhat subjective. The number of conclusive tests on which each rating is based appears in parentheses after the index.

The tests are not tests of materials alone, but rather of techniques, which include seeding patterns, weather factors, material amounts, and material properties. The widest divergence in these other factors was probably in the amounts of materials used. For example, the volume of ammonium nitrate/urea/water solution in the tests shown in Table 6 ranged up to 2,700 gallons. One gallon of this solution contains approximately 10 pounds of dissolved solids. Thus, the treatment ranges up to 13.5 tons of hygroscopic solids, versus typically 1 ton of the various powders used.

Of the 45 tests in Table 6, four individually were given a rating of 3, indicating operationally useful clearing. Of these four completely successful tests, three used ammonium nitrate/urea/water (9:1) solution, and the fourth used ammonium nitrate solution. Because a given volume of water can dissolve more of the ammonium nitrate/urea mixture than of either individual component separately and thus produce a more hygroscopic solution, the apparent superiority of the 9:1 solution over either single-component material in Table 6 is a logical result consistent with theory.

Among the powders, the performance of calcium chloride is somewhat surprising. *If* all factors (particle size, amount, flight patterns, weather, etc.) were equal, we would expect calcium chloride to be a more effective agent than sodium chloride and especially urea. This judgment is based on the greater hygroscopicity of calcium chloride. The optimum test technique for calcium chloride was perhaps not employed; one could argue that anhydrous calcium chloride should be injected a considerable distance below fog tops to properly utilize the rapid heat release from hydration. An examination of the test results revealed several factors that may explain the apparent results of tests with calcium chloride powder compared to tests with other agents. First, the number of tests with other agents is small, and therefore the average depends strongly on a single test. Second, the location of testing for calcium chloride powder, over the ocean, did not allow taking certain observational data routinely available at the airport, where the urea test was conducted. Consequently, in the calcium chloride tests fewer kinds of data implied fewer chances to detect results if they occurred. The effectiveness of the urea was ascribed mainly on the airport transmissometer trends and LWC reduction from low-level Minilab passes. Judged solely from topside visual effects, the results of the urea test were not as impressive as the rating would imply.

Another factor that serves to reduce the average effectiveness of the calcium chloride is the small amount of material used in some tests, as little as 400 pounds. This dosage was sometimes planned and sometimes the result of jamming of the dispensing system.

Most of the individual tests produced definite modification of the fog or stratus deck, but the results fell short of producing consistent, operationally useful clearing. The various tests with the ammonium nitrate/urea/water spray gave the most dramatic results, even though success was not consistently achieved completely with these methods either.

With both powders and sprays, seeding patterns included dumbbells, racetracks, straight lines, and orbits. Most seeding was conducted with the seeding craft skimming the tops of the lowest cloud layer, although a few tests used seeding altitudes a few hundred feet below this cloud-top level. Using an in-cloud seeding level eliminates the value of topside photo/visual observations, and restricts analysis to data obtained in or below the cloud. No absolutely clear superiority of a certain flight pattern was evident in the test results, but it seemed that repeated treatment to concentrate the seeding material caused the highest degree of clearing.

The four most successful tests were conducted over the airport. However, in those cases, the holes that formed would have been evident even if the tests were conducted elsewhere over the sea or remote land areas.

Ground-Based Tests

Only one test was run with ground-based equipment. This test used the Fog Sweep device, which dispensed about 10 gallons of 9:1 solution before mechanical problems forced termination. No results of seeding would be expected from this small amount of material, and none was observed.

Several demonstrations were run with the Fog Fan device, including one in fog, again using 9:1 solution. Some evidence of improved visibility downwind of the seeding site was noticed by observers walking arcs a few hundred feet from the Fog Fan. The effects were definite, but too slight to be considered of operational significance. In this demonstration, the plume of seeding spray was not visually distinguishable from fog above about 150 feet. Drops of spray material falling out downwind were larger than the drop sizes emitted by the nozzles.

SUPPORTING TESTS

Besides the 72 seeding tests reported above, 41 supporting tests were run. These tests yielded data on equipment performance, test techniques, data-gathering methods, and weather. The important findings are described in this section.

It was found that fogs and stratus clouds at Arcata show surprisingly high liquid water contents. Average values of 0.2 or 0.3 g/m^3 would have been predicted before the project, but many times the preseed Minilab data showed values of as much as 1.0 g/m^3. Perhaps some of these values could be ascribed to instrument error, but most of them are believed to be accurate, being qualitatively corroborated by visual observations of water collecting on project aircraft components and by natural drizzle falling from stratiform clouds topping out at 2,000 feet MSL or less. Often, but by no means always, those parts of the cloud or fog at the seaward side of the airfield were found to be richer in liquid water than portions of the same layer at the same altitude just slightly farther inland. This phenomenon may be related to upward vertical motion occurring over the bluff at this location. This motion could cause small pockets of air to undergo additional condensation as the air moved onshore. Conceivably, these small, wet pockets would then become mixed and diluted by diffusion on moving farther inland. This localized enrichment of liquid water content often contributed to the "noise" in preseed data and difficulties in finding seeding effects in LWC values.

The gelatin-coated-slide technique for replicating precipitating droplets was studied from several standpoints. It was desirable to learn whether replication varied with the mechanics of the technique. In brief, no effects of aging prepared slides were found, nor were effects found due to storing exposed slides before reading them. A recipe of 1 or 1 1/2 teaspoons of clear gelatin to 6 ounces of distilled water was suitable.

Tracking the plumes of seeding materials proved a difficult problem, but one that is ever present in tests where the laboratory aircraft attempts to gather comparative data in and out of the treated part of the cloud. An electric-field meter was able to detect the airborne pyrotechnic smoke directly overhead, but this ground-based instrument was not able to track the smoke as it blew away. Attempts to mark the cloud at the points along the seeded path by using colored smoke grenades did not prove fruitful. The material rapidly diffuses and becomes indistinguishable. For topside seeding, the formation of aircraft wakes often helped locate the seeded portion of the cloud. Even when not releasing any seeding material, an aircraft usually leaves a wake, which was measured in one test as 1.5 wingspans wide. Such wakes usually persist for a few minutes, and are increased severalfold when the aircraft releases a hygroscopic material.

For in-cloud tracking, a device was built and tested briefly, with promising results. This consisted of an ohmmeter-type device that was exposed to the fog and wired into the Minilab circuit. As conductivity changed, a signal was recorded having rapid "on" and "off" response.

The most frequent kind of extra test run during the project was that to determine the size of spray droplets emitted by the various kinds of nozzles used in airborne tests, as well as other characteristics of the pumping system. Results appear in Table 7.

TABLE 7. B-25 Spray System.

Indicated airspeed, 130 knots.

Nozzle size, in.	Nozzle pressure, lb/in²	Flow rate, gal/min	Modal[a] diam.[b], μ	Diam. of largest drops, μ
1/16	70	47 1/2	140	360
1/8	60	160	180	420
3/16	40	267	55[c]	460
1/4	20	400	160	390
0.040 sawcut	60	160	170	470

[a] Highest frequency of drop sizes.

[b] Drop slide crater size from spray passes 50 feet above the ground.

[c] First test. Second test not significantly modal; ranged from 50 to more than 420 μ.

TEST RESULTS

A summary of the 72 tests run is given in Appendix D, Table D-1, which shows to some degree the variety of materials tested and the various conditions of testing. Table D-2, Appendix D, shows ceiling and visibility readings. In many instances the information is incomplete and in others the test was made away from the airport so that no change in ceiling and visibility information was obtained.

Case descriptions are given for tests 30, 44, 46, 62, 64, 65, 67, and 71 in the following pages. These tests were picked to illustrate certain

TABLE 8. Amounts of Material by Weight Dispersed Into Fog for Selected Tests.

Test	Material	Total amt., lb	Equivalent solid, lb	Dispensing rate, lb/min	Equivalent solid, lb/min
30	Ammonium nitrate [a]	8,600	5,160	1,770	1,062
44	Calcium chloride powder	800	800	75-200	75-200
46	Sodium chloride [b]	2,000	2,000	670-1,000	670-1,000
62	9:1 solution	8,550	7,695	2,280	2,052
64	9:1 solution	8,550	7,695	2,132	1,919
65	9:1 solution	8,550	7,695	1,140	1,026
67[c]	9:1 solution	4,560	4,104	1,140	1,026
71[d]	9:1 solution	31,400	28,300	1,940-2,280	1,746-2,052

[a] 60% solution by weight.
[b] Morton's V.F. 50/50.
[c] Cumulus seeding test.
[d] One B-26 and two C-123s.

features of interest in each test. Generally, the idea is to show the results of the best tests with ammonium nitrate solution (Test 30), calcium chloride powder (Test 44), salt (Test 46), and the 9:1 solution (Test 65), and to show a cumulus test (Test 67). Tests 62, 64, and 71 illustrate additional 9:1 solution results. The amounts of material that could be dispensed in powder form were less than could be handled as a solution. The amounts and dispersing rates for the selected tests are shown in Table 8. In intercomparing the tests, the results may be expected to differ, because of the different amounts of material or rates of dispensing.

Test 30 (1 August)

1. Seeding
   a. Time: 0835 to 0844
   b. Amount and Material: 800 gallons of ammonium nitrate solution
   c. Pattern: Three orbits 1 mile in diameter
   d. Altitude: On top of 1,000- to 1,200-foot-thick fog
   e. Dispensing Rate: 165 gal/min
2. Ground Station Data

a. Weather Office: The weather had been ceiling zero and visibility 1/16 mile at 0710 and had improved to ceiling 100 feet and visibility 1/4 mile when seeding began at 0835. At 0858 it was ceiling 200 and visibility 3/4 mile, and at 0915 it was up to ceiling 300 feet and visibility 1 1/2 miles. It continued to improve during the morning.

b. Transmissometer: The transmissometer reading was 35% before seeding and increased to 90% after seeding. There was a clearing trend before seeding began.

c. Special Ground Stations: Observers reported some increase in visibility in the seeded area, but no holes developed. A photographer took a picture of the solar disk, which was visible to the eye, but the photograph did not turn out. No large droplets of solution were felt, but white specks of material were noticed on eyeglasses of observers in the seeded area, indicating droplets of solution. The Minilab aircraft was seen on its second postseed pass.

3. Aircraft Data

a. Aerial Photographs: Aerial photographs show no effects of seeding other than normal distrails.

b. Visual Observations: Visual observations by the pilot of the Minilab aircraft showed that an area of thin fog with greatly increased visibility was encountered in the seeded area on the second postseed pass at 420 feet altitude. The Minilab observer saw the beach and highway from 900 feet on his first postseed pass. He estimated the ceiling was 200 feet higher in the seeded area, with greatly improved slant range. Buildings and people were observed on the ground.

c. Minilab Data: The Minilab data showed that there was not much change in temperature, dew point, and liquid water content from the preseed to the postseed passes, until on the third postseed pass the liquid water content went from 1/3 g/m^3 to spikes of 1 to 1 1/2 g/m^3.

d. Drop Size and Distribution: Station 1: Slight decrease in median drop size (36 to 29 microns) against increasing size trend. Large increase in drop density (≈2,000) and back down to preseed value as compared with a decreasing trend. Station 2: Median drop size remained constant throughout seed period at 38 microns with a large increase to 61 microns 20 minutes after seeding. Drop density increased slightly at seed. Station 3: Median drop size increased from 38 microns to 54 microns at seed, then decreased to 43 microns. More markedly, drop sizes above the 25% value increased from 44 microns to 108 microns and then decreased to 54 microns. Drop density decreased slightly (factor of 5) and then went back up to the original value.

Station 3 was 500 feet inside the southwest edge of orbit, Station 2 downstream from orbit; seeded fog should have passed over Station 1 also. Nearest orbital segment to Station 2 is ≈1,700 feet and to Station 1, 2,900 feet.

In Fig. 18 and 19 are shown the plots of drop sizes versus time and relative drop density versus time for each of the ground stations. These show the change in drop sizes and amounts during the test.

Test 44 (5 September)

1. Seeding
   a. Time: 0836 to 0902
   b. Amount and Material: 800 pounds of calcium chloride powder
   c. Pattern: Four passes in racetrack pattern
   d. Altitude: At cloud tops, 2,250 feet
   e. Dispensing Rate: 200 pounds per pass; attempted 100 lb/sec, but difficulties with radar and hoppers delayed last two passes
2. Ground Station Data
   a. Weather Office: Although this test was done at sea, the weather at Arcata-Eureka airport at seeding time was ceiling, indefinite, 200 feet, obscured; visibility, 1 mile, with light drizzle; sea-level pressure, 1,016.6 millibars; temperature, 59°F; dew point, 57°F; wind direction, 280

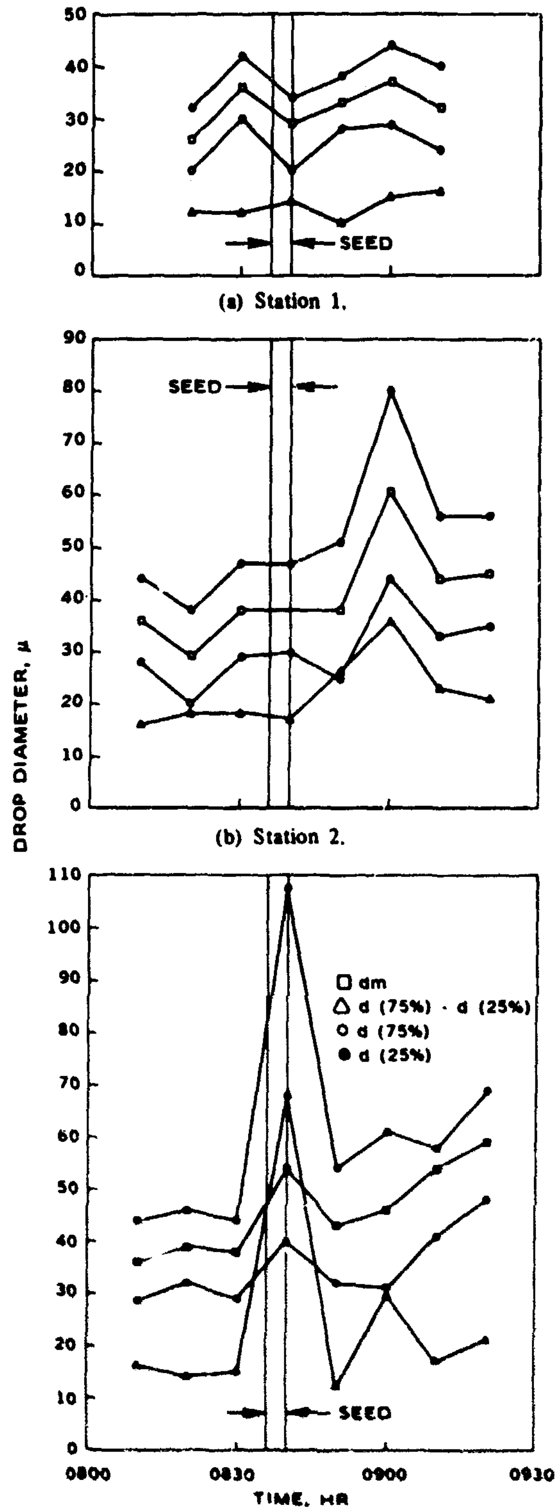
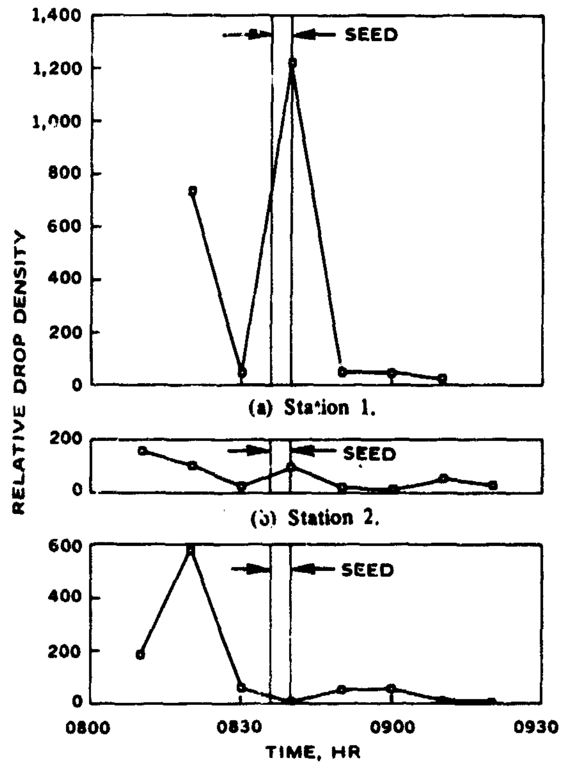


FIG. 18. Drop Size, Test 30.



(c) Station 3.

FIG. 19. Relative Drop Density, Test 30.

degrees at 4 knots; visibility on runway 31, 6,000 feet plus, conditions changeable.

b. Transmissometer: Transmissometer readings do not apply.

c. Rawinsonde: The sounding taken at Arcata-Eureka airport 7 minutes before seeding time is shown in Fig. 20.

d. Special Ground Stations: Observations taken by the boat crew gave cloud bases at 500 to 800 feet, with visibility greater than 5 miles. The clouds were naturally irregular, with light drizzle most of the time. Although the seeder aircraft had been seen on its second pass on Test 43, it was not sighted during this test, but it was heard occasionally.

3. Aircraft Data

a. Aerial Photographs: The aerial photographs show the seeder aircraft dispensing the powder; the distrails were somewhat wider than normal and lasted for 4 to 6 minutes. However, the trails covered over again, and no change was apparent after a few minutes.

b. Visual Observations: Photographs taken with a hand-held Leica camera show the same data as the aerial photographs. The distrails were seen to be fluffy in the center. Observers in the Minilab aircraft noted that the ceilings were higher and more ragged on the postseed passes.

c. Minilab Data: The LWC meter indicated readings increasing proportional to altitude, with observations of sharp, narrow troughs of LWC depression, of the order of 0.2 to 0.3 g/m^3, which persisted only 5 to 6 minutes.

d. Drop Size and Distribution: These data were not taken because the boat was out of position for this test.

Test 46 (6 September)

1. Seeding
   a. Time: 0844, 2 1/2 minutes' seeding time
   b. Amount and Material: 2,000 pounds of Morton's fine 50/50 sodium chloride
   c. Pattern: Racetrack 6,700 feet long by 4,100 feet wide
   d. Altitude: 1,800 feet, at cloud tops
   e. Dispensing Rate: 800 lb/min
2. Ground Station Data

a. Weather Office: This test was conducted at sea, but the weather at Arcata-Eureka airport was ceiling, indefinite, 300 feet, obscured; visibility, 3 miles, with fog; sea-level pressure, 1,016.6 millibars; temperature, 58°F; dew point, 56°F; winds, calm. Cloud tops at the seeding site were ceiling, 1,800 feet with bases 900 feet.

b. Transmissometer: Does not apply.

c. Rawinsonde: The information for the rawinsonde sounding taken 31 minutes after seeding time is shown in Fig. 21.

d. Special Ground Stations: The boat was late in arriving on station, so that it arrived in the seeded area at 0910, about 25 minutes after seeding. A small bright spot was observed in the clouds, but blue sky was not seen. The spot lasted about 10 to 15 minutes and collapsed by diffusion.

3. Aircraft Data

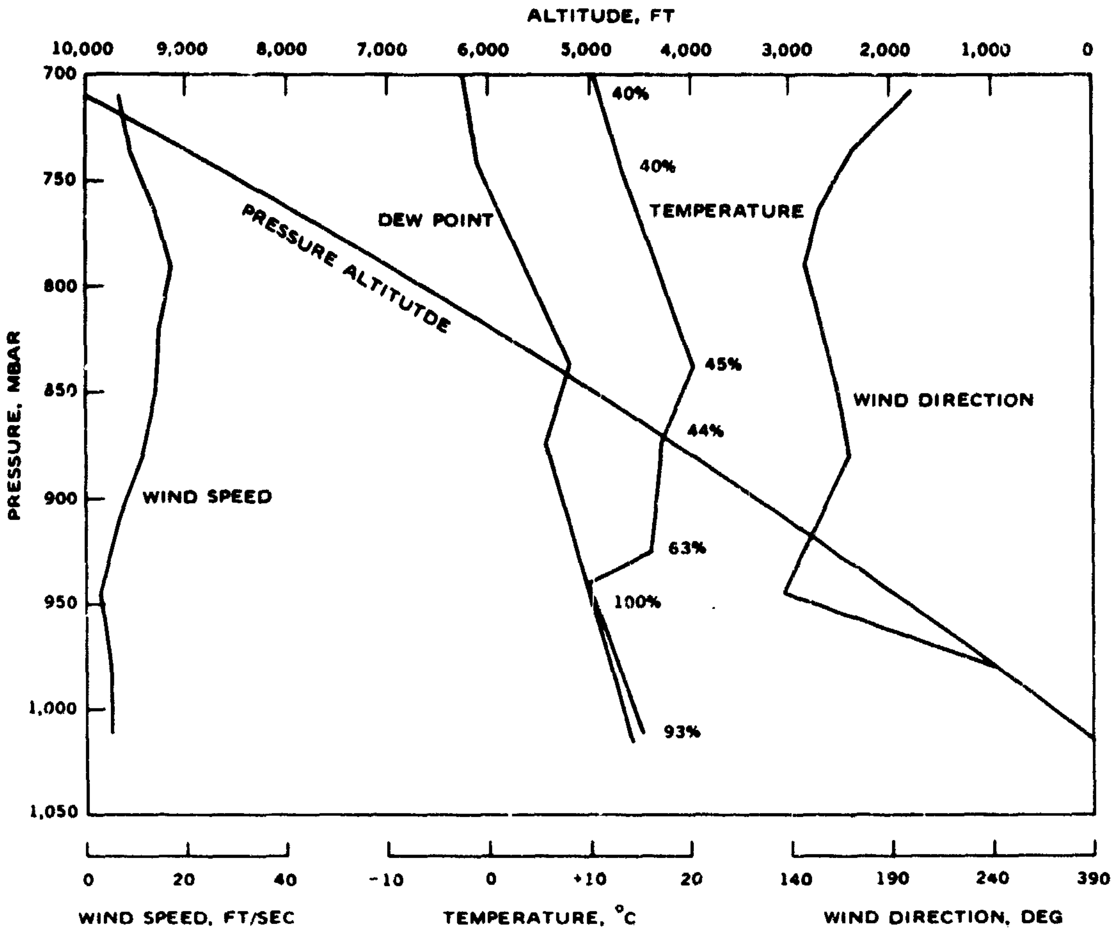


FIG. 20. Rawinsonde Data, Test 44.

a. Aerial Photographs: No effects of seeding other than distrails are apparent in the aerial photographs.

b. Visual Observations: There were some openings observed in the fog layer before seeding, such as whorls and eddies, but these did not go through the fog layer. Immediately after seeding, the distrails opened normally and became very deep. The trails were narrow and sharp 2 to 3 minutes after seeding, but no holes clear through were observed.

c. Minilab Data: The Minilab aircraft made six passes, with liquid water content varying smoothly from 0.8 to 0.1 g/m^3 on a sounding pass through the layer from top to bottom. On the second postseed pass, three areas of liquid water content greater than 2.0 g/m^3 were encountered at about 8 minutes after seeding. During the later passes, however, the liquid water content was as before. Temperature and dew point variations are shown in Table 9.

d. Drop Size and Distribution: No droplet slides were made from the boat.

Test 62 (9 October)

1. Seeding
   a. Time: 1005 to 1016
   b. Amount and Material: 750 gallons of 9:1 solution
   c. Pattern: Dumbbell
   d. Altitude: 800 feet
   e. Dispensing Rate: 200 gal/min
2. Ground Station Data
   a. Weather Office: This test was done at sea;

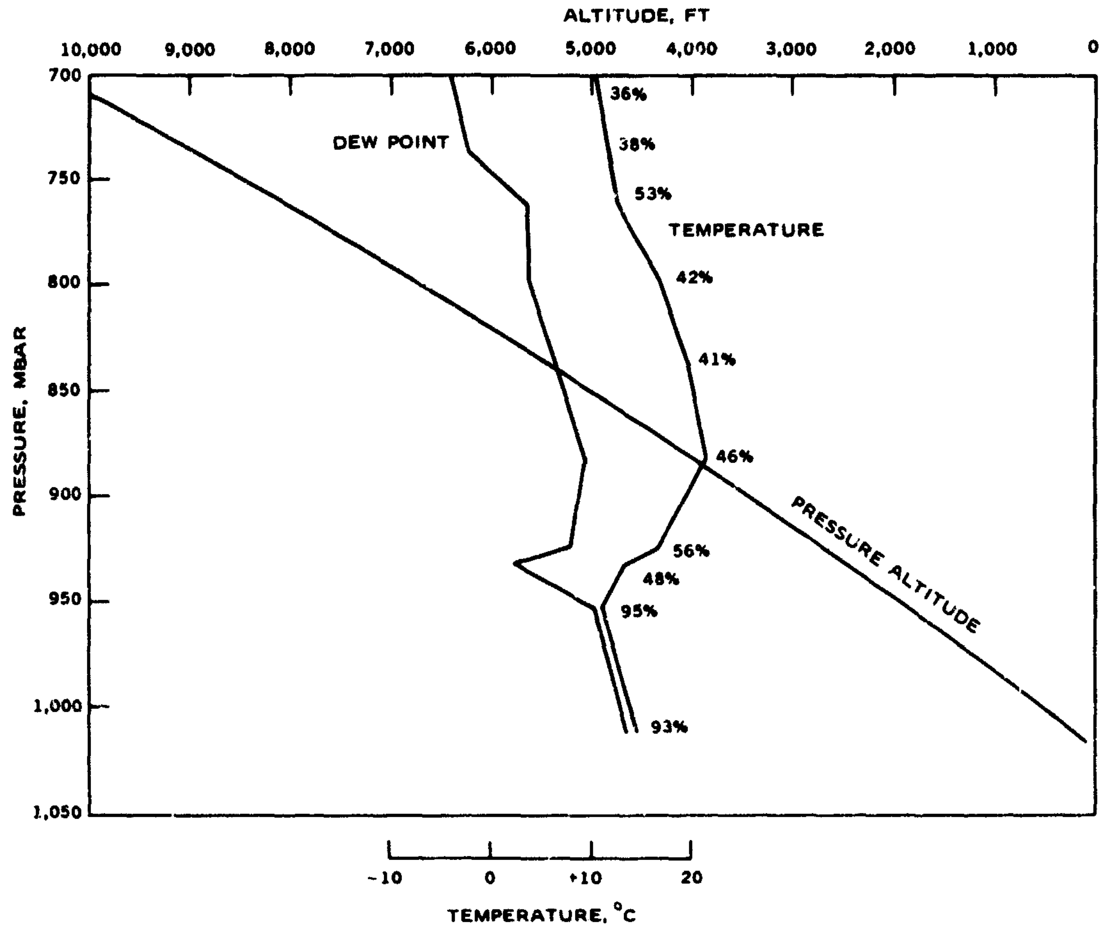


FIG. 21. Rawinsonde Data, Test 46.

TABLE 9. Temperature and Dew Point Variations, Test 46.

Pass	Altitude, ft	Temp., °C	Dew point temp., °C	Pressed temp., °C		Postseed temp., °C	
				Temp.	Dew point	Temp.	Dew point
1	1,300	14.2-14.4	11.5-11.8	13.2-13.8	12.1	14.4	11.4
2	1,300	13.9-14.2	11.5-11.2	13.2-13.6	12.1	14.4	11.4
3[a]	960	13.8-13.5	11.2	13.9	12.3	14.7	11.8
4	1,000	14.1-14.3	11.2-11.5	13.9	12.3	14.7	11.8
5	800	14.7-14.9	11.6-11.5	14.0	12.4	14.9	12.0

[a] Temperature agrees with pressed and is not elevated until the next pass at about the same altitude.

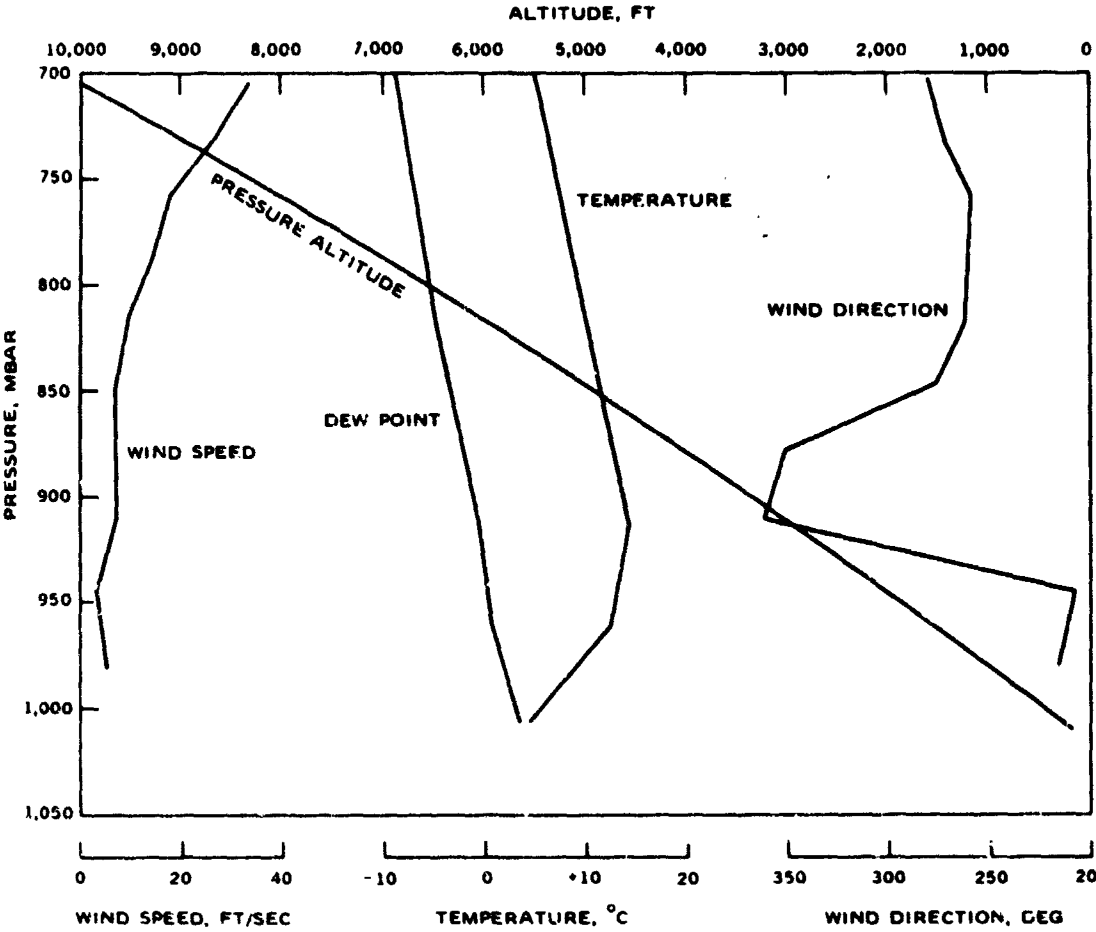


FIG. 22. Rawinsonde Data, Test 62.

however, the weather at Arcata-Eureka airport at seeding time was given as ceiling, 100 feet, thin, broken; visibility, 5 miles, with ground fog and smoke; sea-level pressure, 1,015.9 millibars; temperature, 51°F; dew point, 47°F; wind from 170 degrees at 7 knots, with a bank of shore clouds with changeable conditions.

b. Transmissometer: Does not apply.

c. Rawinsonde: The rawinsonde release was 108 minutes before seeding; data are shown in Fig. 22.

d. Special Ground Stations: The boat crew reported the fog bottom as very smooth and uniform, with the fog down on the water. Seeding was directly above, and bright spots developed in the heretofore dark layer. The boat tried to keep up with the movement of the spots, but was unable to because of the winds. The spots disappeared at 20 to 22 minutes after seeding, and no other spots were observed.

3. Aircraft Data

a. Aerial Photographs: The aerial photographs show nothing of interest.

b. Visual Observations: The observers aboard the control aircraft noted that seeding trails lasted about 5 minutes, and no depression developed, so that nothing unusual was sighted. The Minilab observer reported thinning of the area where seeding took place, and on the sixth and seventh passes at 25 and 28 minutes after seeding noted he could see the ocean and blue sky at the same time. It had closed in again by the eighth pass, however.

c. Minilab Data: On the preseed Minilab

passes, the liquid water content at 200 and 500 feet below the tops was running at about 1/2 and 1/3 g/m^3, respectively. In the first postseed pass, it was 1.5 g/m^3 at 200 feet below the tops, with a strong peak of 6.1 g/m^3. On the second postseed pass at tops minus 200 feet, the reading was 0.7 to 1.9 g/m^3. In the next three passes at 500 feet below the tops, the average liquid water content was 0.3 g/m^3, with peaks superimposed of 1.3, 2.2, and 0.5 g/m^3, respectively. This would seem to indicate a picture of the treatment, augmented by fog water, falling through the cloud. Figure 23 shows preseed and postseed liquid water content.

d. Drop Size and Distribution: No slides were taken. The boat crew tried to follow the bright areas, which were moving rapidly with the wind. They noted no fallout or precipitation.

Test 64 (24 October)

1. Seeding
   a. Time: 0856 to 0900
   b. Amount and Material: 750 gallons of 9:1 solution
   c. Pattern: Four circular orbits
   d. Altitude: At cloud tops, 900 feet
   e. Dispensing Rate: 187 gal/min
2. Ground Station Data

a. Weather Office: The weather at seeding time was ceiling, zero; visibility, 1/16 mile. Observations at 0830 were sea-level pressure, 1,010.2 millibars; temperature, 10.0°C; dew point, 9.4°C; relative humidity, 96%; ground winds from 200 degrees at 5 ft/sec, winds at tops, 140 degrees at 7 ft/sec, the mean winds from 195 degrees at 8 ft/sec.

b. Transmissometer: The transmissometer reading was less than 1,000 feet at seeding time and went abruptly to 2,800 feet about 15 minutes after the end of seeding. It started downward at 22 minutes and was again less than 1,000 feet at 26 minutes after the end of seeding and continued so for an hour and 15 minutes.

c. Rawinsonde: A balloon release at 0830 showed that the cloud bases were on the ground and the tops were at 880 feet.

d. Special Ground Stations: Ground observers at the CB area (see Fig. 3) reported seeing the seeder aircraft as it completed seeding. There were small improvements in ceiling and visibility noted, which did not last long. Spray droplets were felt by the tower observer a few minutes after seeding.

3. Aircraft Data

a. Aerial Photographs: The photographic aircraft took color photographs of the seeded area. The hole that was reported by the seeder aircraft pilots, the Minilab observer, and the photographer is visible (Fig. 24), but the quality of the prints is poor and no features on the ground can be observed.

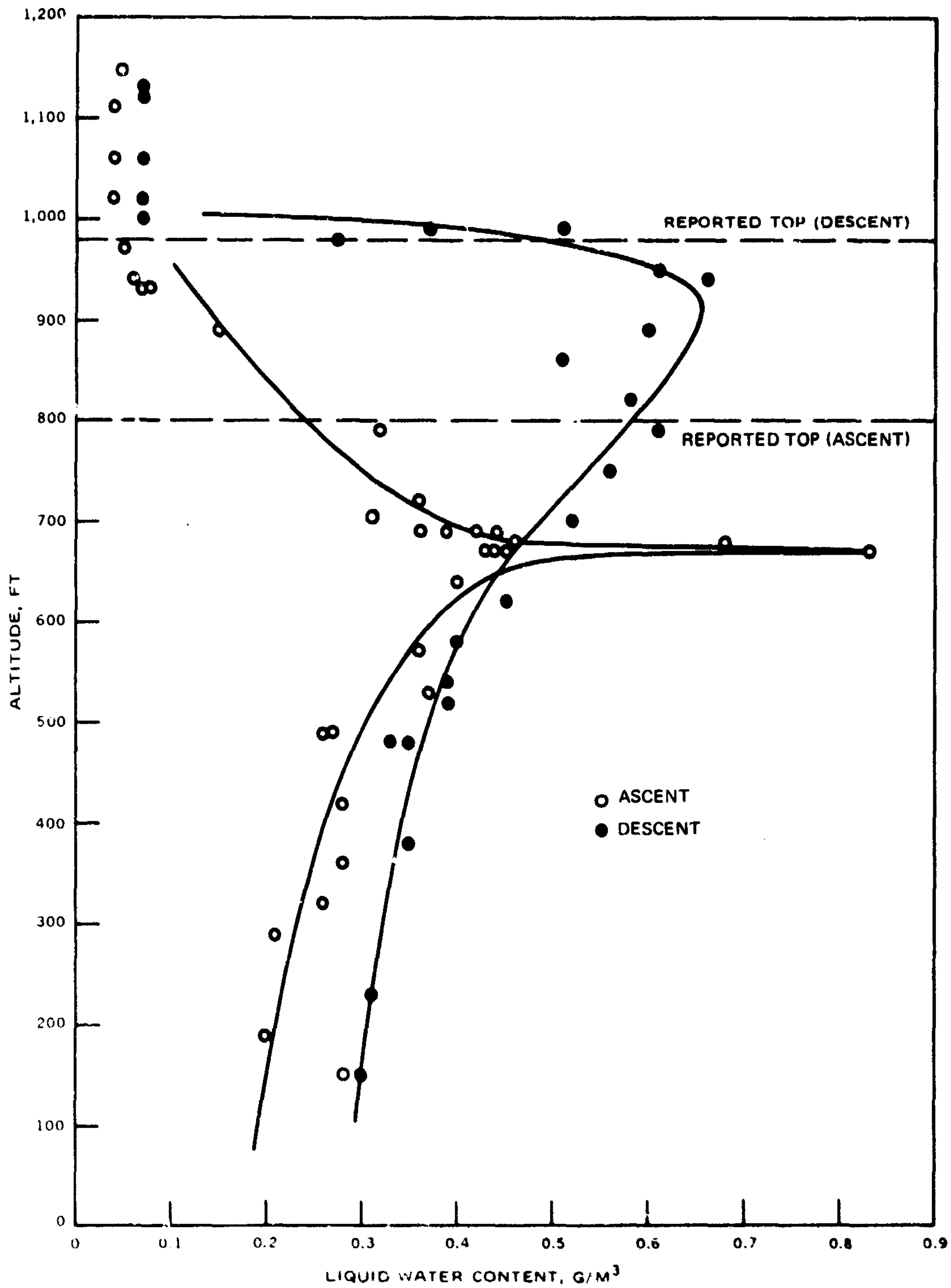
b. Visual Observations: The seeder aircraft pilot reported sighting the ground about the time seeding ended, and he and the copilot could see an aircraft parked on the airport runway, and the beach area to the north. The opening was 1/2 mile in diameter and lasted about 10 minutes. The observation aircraft reported the hole was disk-shaped with a 3/4-mile diameter in the depressed area. The distrails generated during seeding were much deeper than normal. The photo aircraft took six color photographs of the seeding and the opening and closing of the hole. The Minilab observer saw the hole during his passes and could see the runway as well as the airstrip intersection and the glide-slope antenna. He reported that the ceiling over the runway raised more than 200 feet.

c. Minilab Data: The Minilab records showed no changes in liquid water content, but a depression of the dew point temperature indicated a drying effect from the preseed to postseed conditions.

d. Drop Size and Distribution: Droplets of solution were detected by the ground stations a few minutes after seeding.

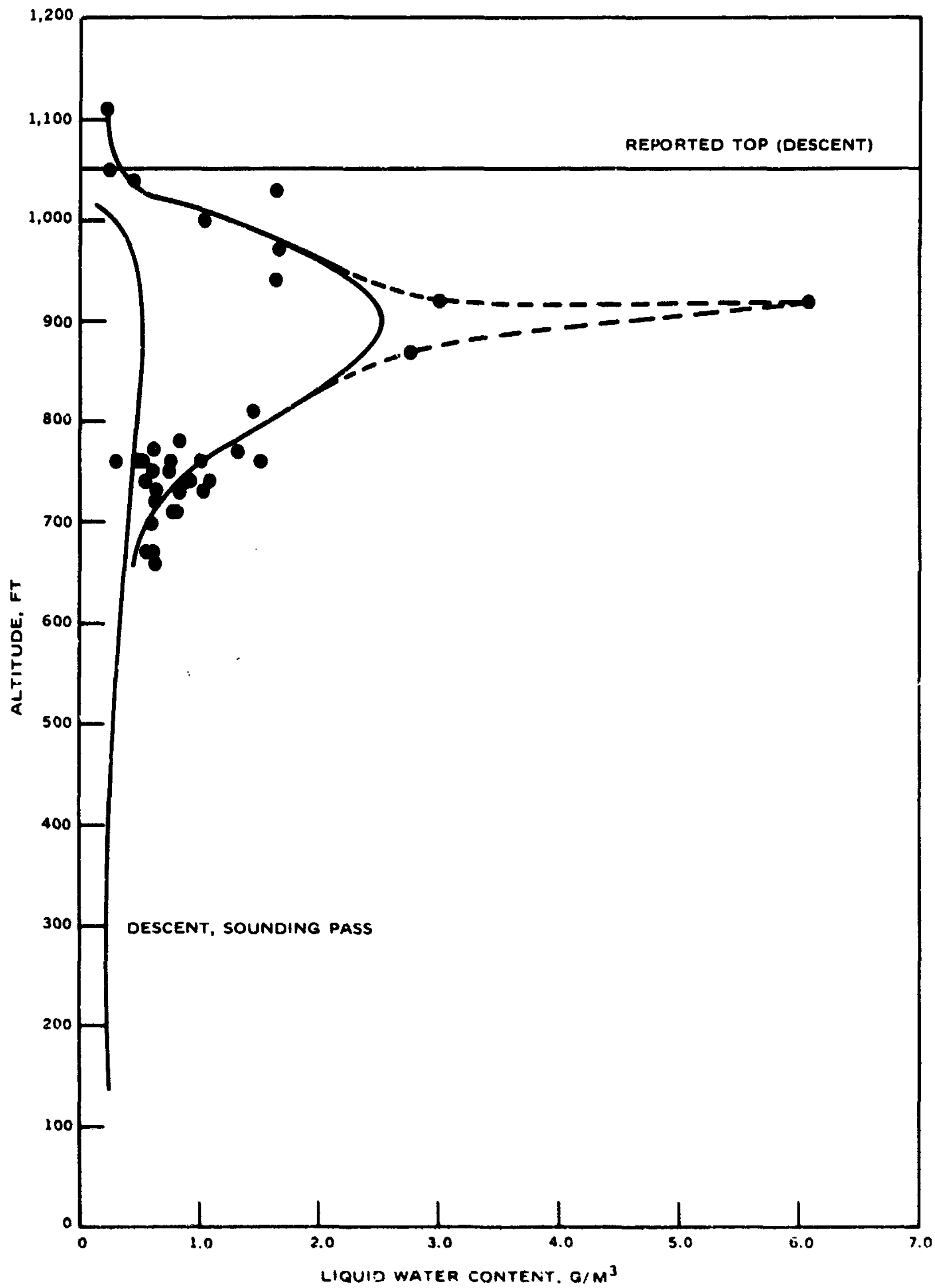
Test 65 (25 October)

1. Seeding
   a. Time: 0815 to 0839
   b. Amount and Material: 750 gallons of 9:1 solution
   c. Pattern: Dumbbell, 12 passes with left boom only
   d. Altitude: 700 to 1,100 feet
   e. Dispensing Rate: 100 gal/min
2. Ground Station Data



(a) Preseed.

FIG. 23. Liquid Water Content, Test 62.



(b) Postseed.

FIG. 23. (Contd.)

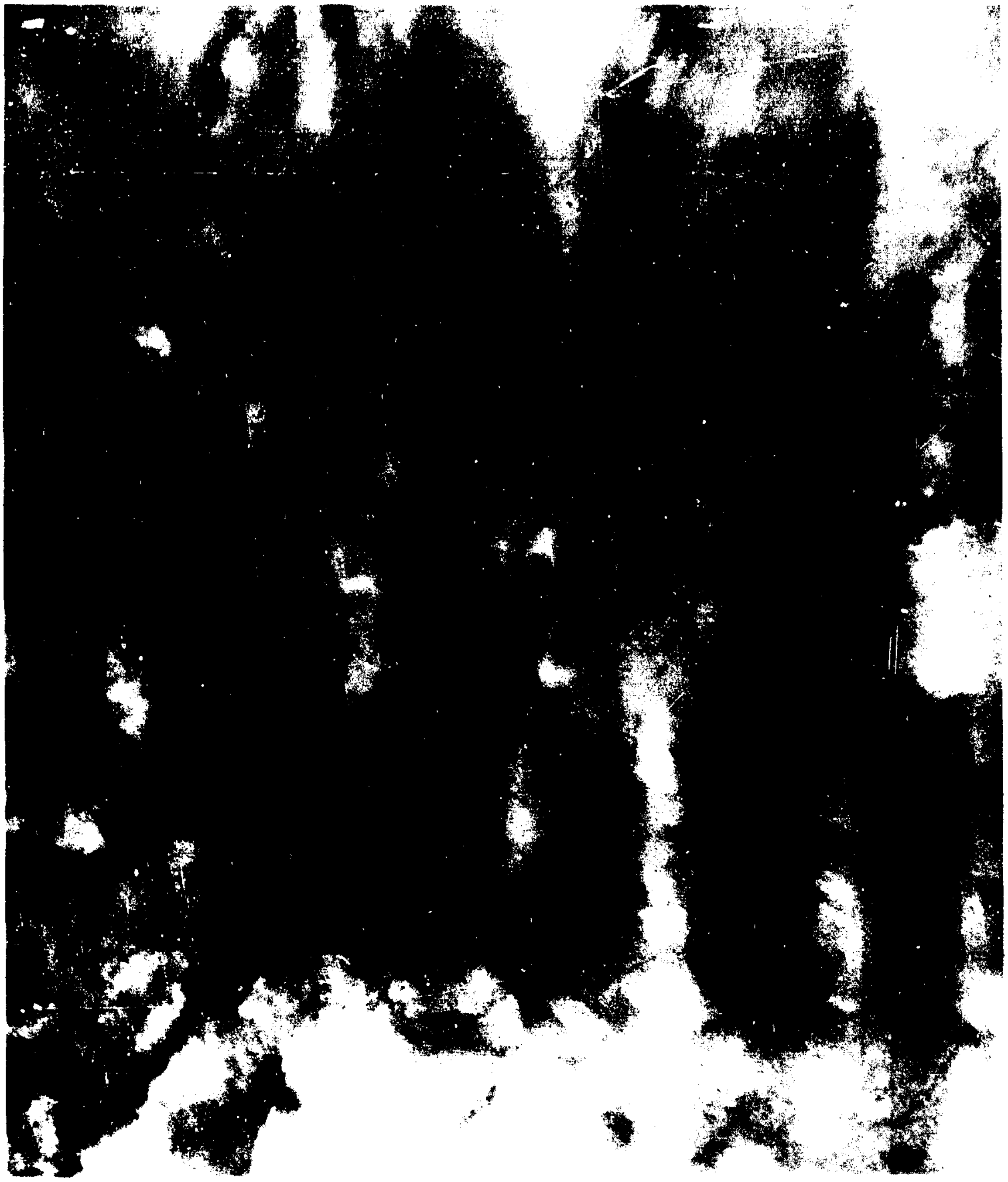


FIG. 24. Hole Generated in Test 64.

a. Weather Office: Conditions before seeding were ceiling, zero; visibility, 1/8 mile; sea-level pressure, 1,022.0 millibars; temperature, 47°F; dew point, 47°F; and winds, calm. The observation made at 0854 showed partial obscuration, visibility 1/4 mile in fog, and at 0910 the report was partial obscuration with 3/4-mile visibility. This went down rapidly at 0915 to ceiling 100 feet,

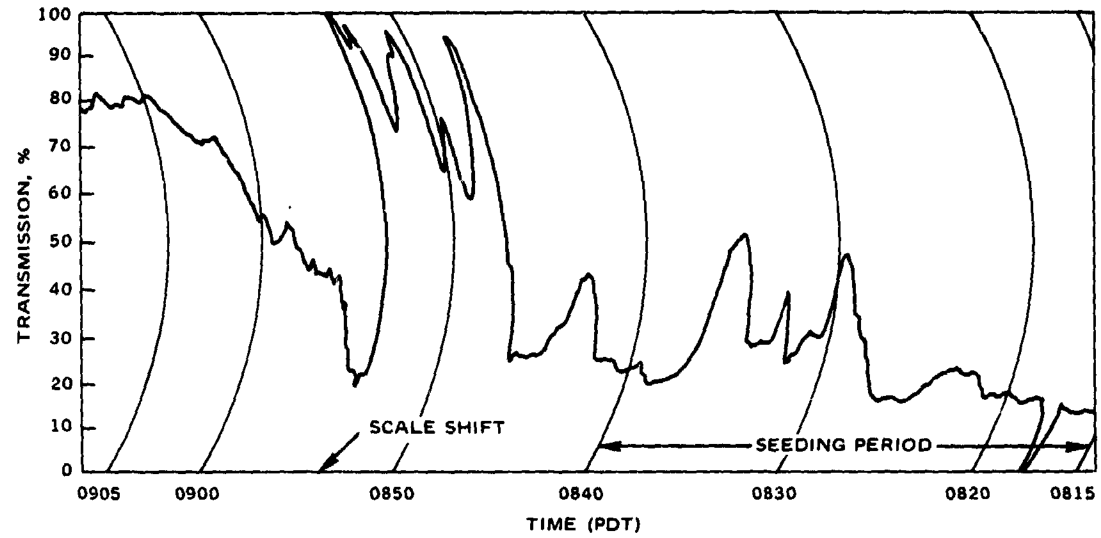


FIG. 25. Transmissometer Data, TF Right, Test 65.

visibility 1/4 mile in fog.

b. Transmissometer: The transmissometer record from TF right shows a large percentage increase from less than 10 to 90%. Figure 25 shows the transmissometer record during seeding and thereafter. The "scale shift" denotes a change in sensitivity as the instrument switches from 10% visibility full scale to 100% visibility full scale. There is some indication of slight natural weakening of the fog before seeding time in areas away from the airport, such as recession of the fog from the hills. All six transmissometers were affected differently in percentage improvements. The readings went from less than 1,000 to greater than 6,000 feet during the test.

c. Rawinsonde: The 0535 release showed temperature and dew point at 9.5°C decreasing to 7.5°C at 750 feet and then rising to 10°C at cloud tops, 1,200 feet MSL. The 0845 release, at 30 minutes after start of seeding, showed temperature and dew point at 8.3°C, with dew point remaining nearly constant, but temperature rising to 18°C at 4,200 feet. Thus the relative humidity was less than 100% with increase in altitude, indicating clearing. The situation is depicted in Fig. 26.

d. Special Ground Stations: Ground observers reported a brightening of the sky with the formation of a hole overhead at about 0845, 5 minutes after the end of seeding. The visibility was unrestricted vertically; blue sky could be seen. Project aircraft were sighted, and the sun was seen. A heavy fallout of droplets occurred. The hole lasted about 30 to 40 minutes, and then the fog returned to preseeding levels of density. It seemed to the ground observers that the fog diffused back in over the airport. However, the C-47 aircraft crew reported the fog moving into the hole would disappear, indicating an area of subsaturation. The C-47 took off during the clearing.

The tower operators were greatly impressed by the apparent results of the test, and submitted a statement citing the improvement in runway visibility readings, from less than 100 to more than 6,000 feet during the test.

One ground observer drove an automobile to Route 101 to the south through McKinleyville and found no effects of seeding or holes except at the airport. He noted solution droplets on the windshield up to more than 1 millimeter in diameter, which continued to absorb water and grow. Conditions were essentially zero obscured and 1/16 mile in fog all the way.

3. Aircraft Data

a. Aerial Photographs: The photographic coverage was terminated at 0845, unfortunately, so that the maximum effects were not covered. Figure 27 shows the clearing at that time, with the end of the runway markings and the numerals

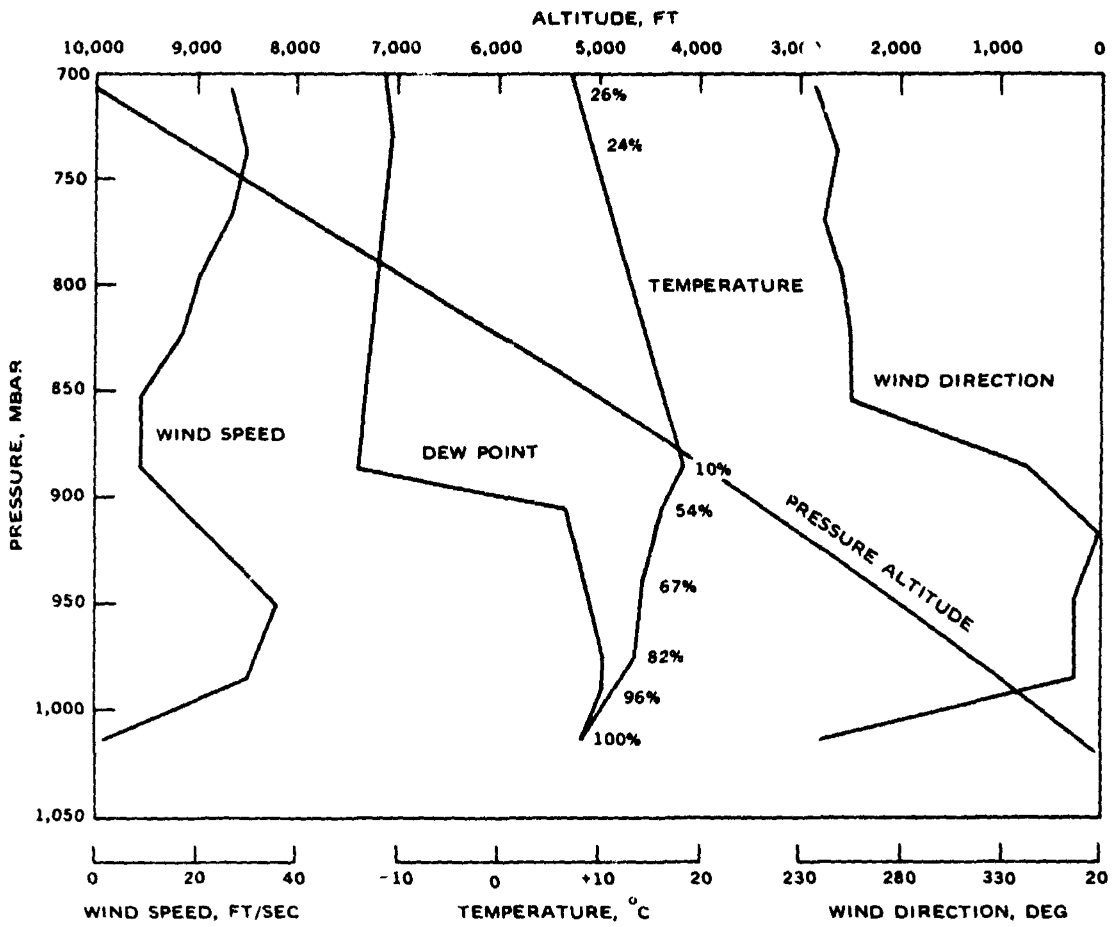


FIG. 26. Rawinsonde Data, Test 65.

13 visible. An aircraft can also be seen.

b. Visual Observations: Airborne observers reported that this was the only hole within 5 miles of the airport. Movie camera footage was made, and the observers noted that the hole drifted toward the ocean. The Leica photographs in Fig. 28 show the preseed, seeding, and postseed conditions, with the runway visible.

c. Minilab Data: The Minilab data showed that the liquid water content before seeding was about 0.15 to 0.30 g/m^3, and after seeding the values were about half of these amounts.

d. Drop Size and Distribution: There was an increase in drop sizes at two of the ground stations, and a decrease in drop density at all the ground stations following seeding. Fallout was felt at Station 1 and at the tower.

Test 67 (30 October)

1. Seeding
   a. Time: 1412 to 1424
   b. Amount and Material: 400 gallons of 9:1 solution
   c. Pattern: Four back-and-forth passes
   d. Altitude: 7,700 feet MSL, 500 feet below cloud tops
   e. Dispensing Rate: 100 gal/min
2. Ground Station Data

a. Weather Office: The weather at Arcata-Eureka airport, approximately 6 miles from the seeded area, was given at 1357 as ceiling, 3,500 feet, scattered, height of cirriform unknown, broken; visibility, 15 miles; sea-level pressure, 1,018.0 millibars; temperature, 58°F; dew point,

FIG. 27. Hole Generated in Test 65. Note numerals 13 and light aircraft.

52°F; winds from 260 degrees at 5 knots; and towering cumulus to the north and south.

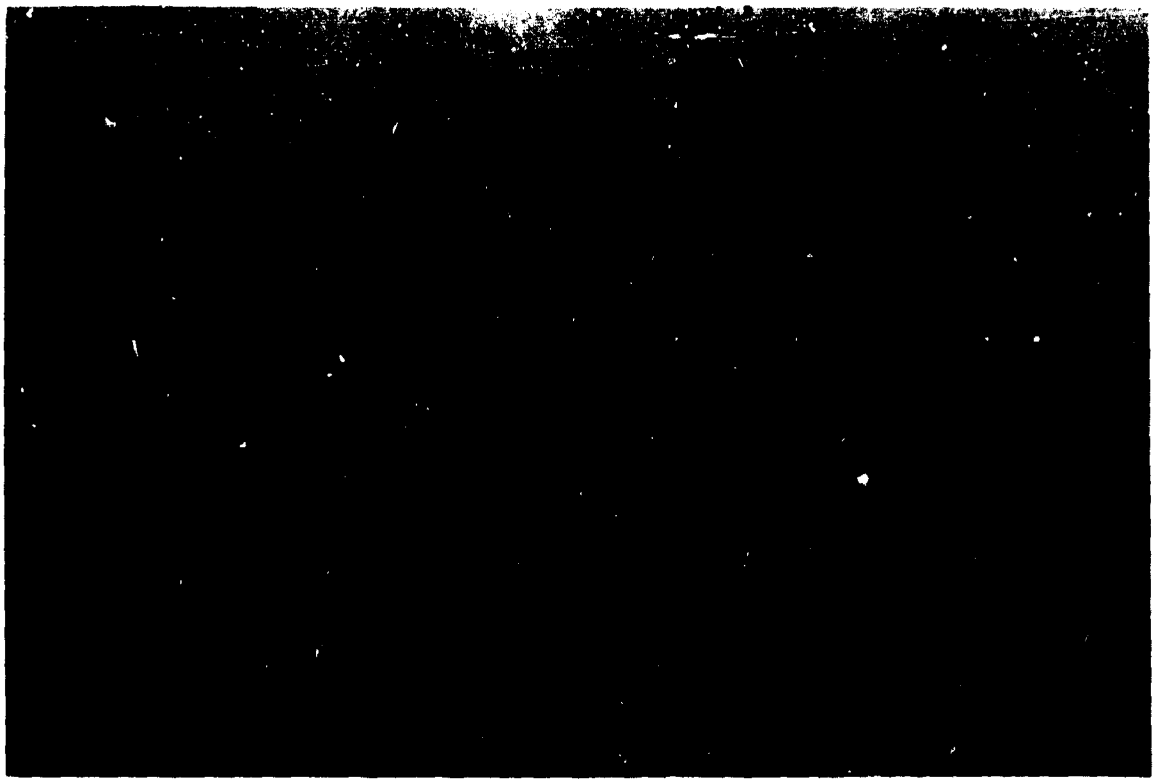
b. Transmissometer: Since this was a cumulus seeding test, no transmissometer or ceiling information was taken.

c. Rawinsonde: The rawinsonde information is shown in Fig. 29. Release time was very close to seeding time.

d. Special Ground Stations: No ground station observations were made as the test was away from the Arcata-Eureka airport.

3. Aircraft Data

a. Aerial Photographs: The aerial photographs were taken at 25-second intervals so that there is not enough overlap between frames for a good perspective. The series shows, however, that after seeding the top of the cloud declined, darkened, and hollowed out in the center, as was



(a) Preseed.

(b) During seeding.

FIG. 28. Preseed, Seed, and Postseed Conditions, Test 65.

(c) Breakup begins.

(d) Hole over runways.

FIG. 28. (Contd.)

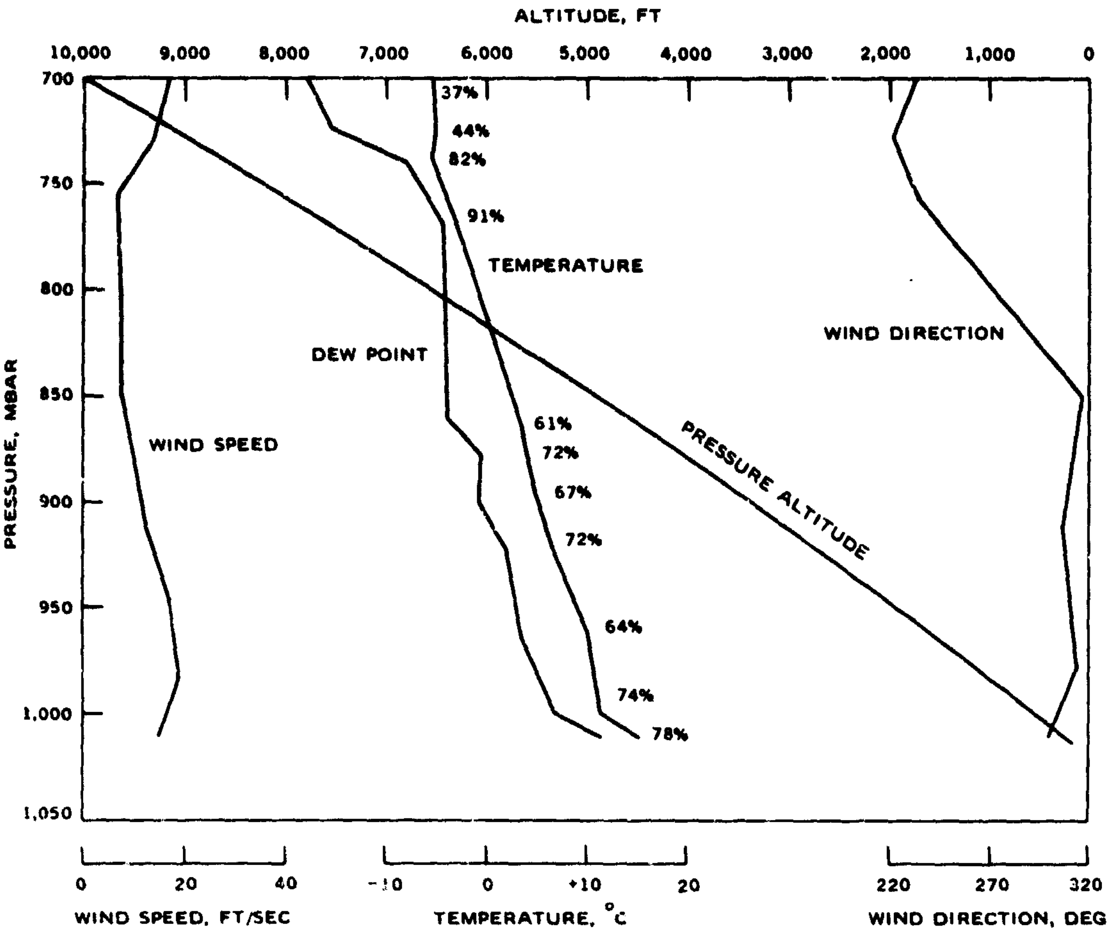


FIG. 29. Rawinsonde Data, Test 67.

reported by visual observers.

b. Visual Observations: The visual observers reported that cloud bases raised and that the tops declined rapidly so that the seeder aircraft seeded an adjacent cloud rather than the original one on its last pass.

The cloud declined for 10 to 15 minutes, and then started to grow again. A series of photographs taken with a hand-held Leica camera is shown in Fig. 30.

c. Minilab Data: The Minilab preseed passes showed little or no precipitation and very light turbulence. On the postseed passes there were areas of large increases in precipitation, accompanied by large amounts of turbulence.

d. Drop Size and Distribution: No data were taken.

Test 71 (9 November)

1. Seeding

a. Time: 0757 to 0810, hold, 0825 to 0846

b. Amount and Material: 2,750 gallons of 9:1 solution

c. Pattern: Racetrack, in trail, with 15-minute hold

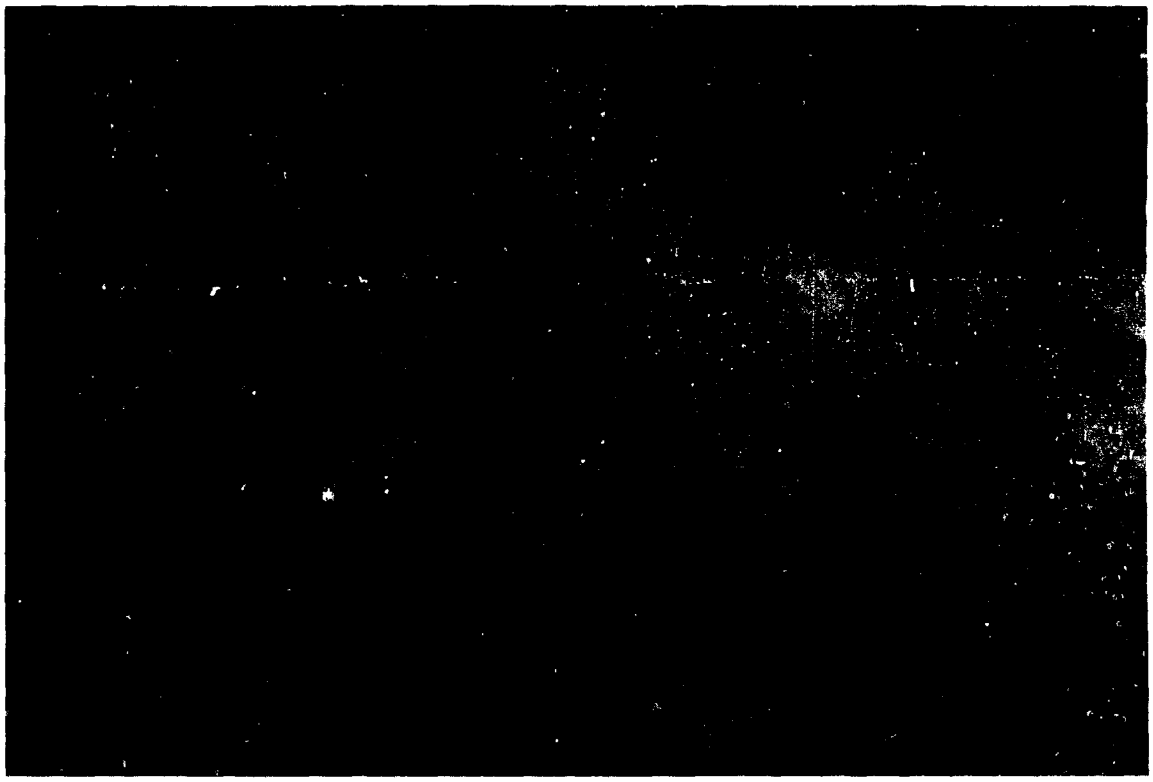
d. Altitude: At cloud tops, 1,200 feet MSL

e. Dispensing Rate: 200 gal/min

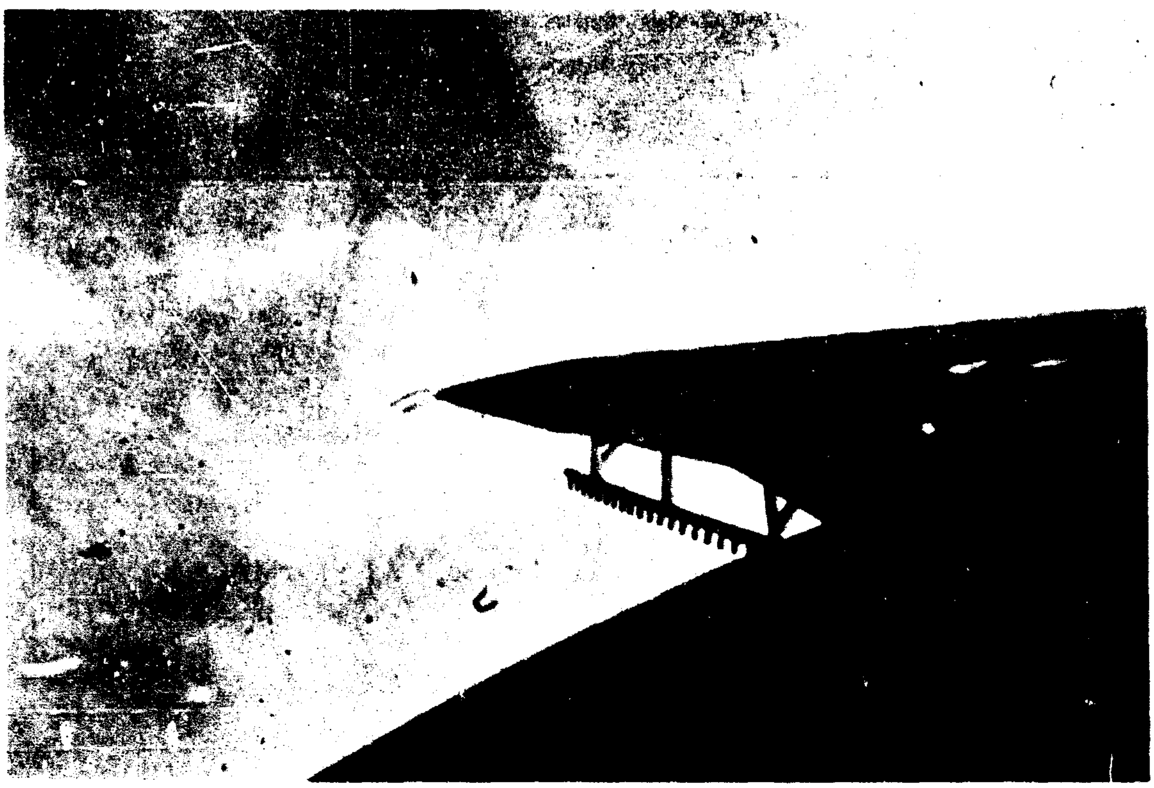
2. Ground Station Data

a. Weather Office: The weather at the time of seeding was ceiling, zero; visibility, zero, with fog; sea-level pressure, 1,024.0 millibars; temperature, 57°F; dew point 57°F; and winds, calm. By the end of seeding, the report was partial obscuration; ceiling, 300 feet, broken; visibility, 1 mile, with fog; winds calm; runway 31 visibility at more than 6,000 feet. At 1028 the field went below minimums, with visibility of 1,400 feet.

b. Transmissometer: The tracing of the TL-2 transmissometer is shown in Fig. 31. The records for others are similar. All were virtually zero for 1 1/2 hours before treatment. Within 15 to 30 minutes after start of seeding all rose sharply to 80% and leveled out. They remained up for about



(a) During seeding.



(b) Tops appear to be dissipating.

FIG. 30. Warm Cumulus Reaction, Test 67.

(c) Base of cloud; stratified layer in foreground.

FIG. 30. (Contd.)

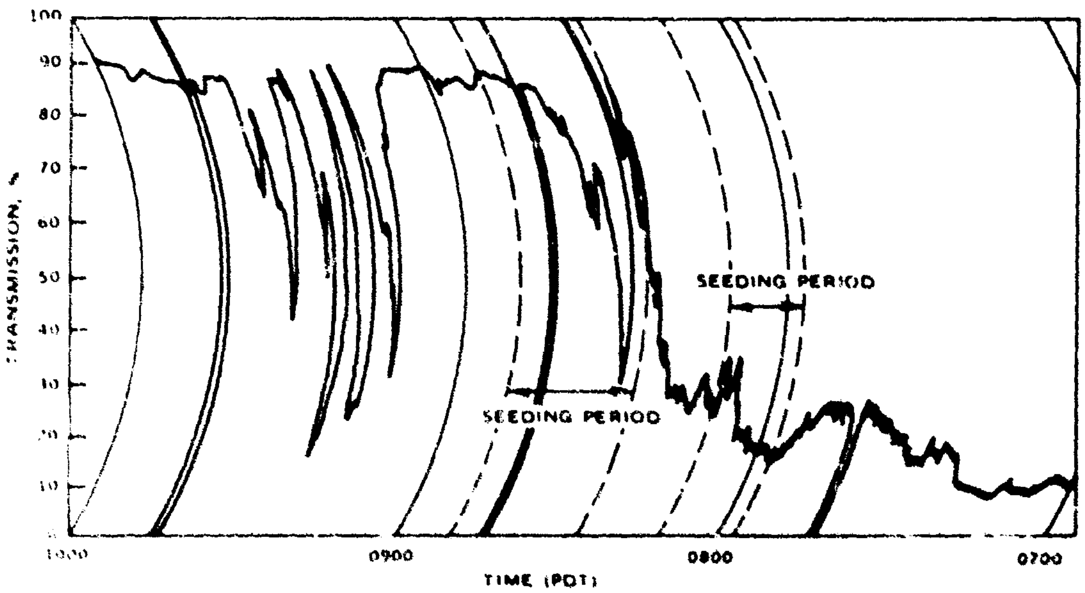


FIG. 31. Transmissometer Data, TL-2, Test 71

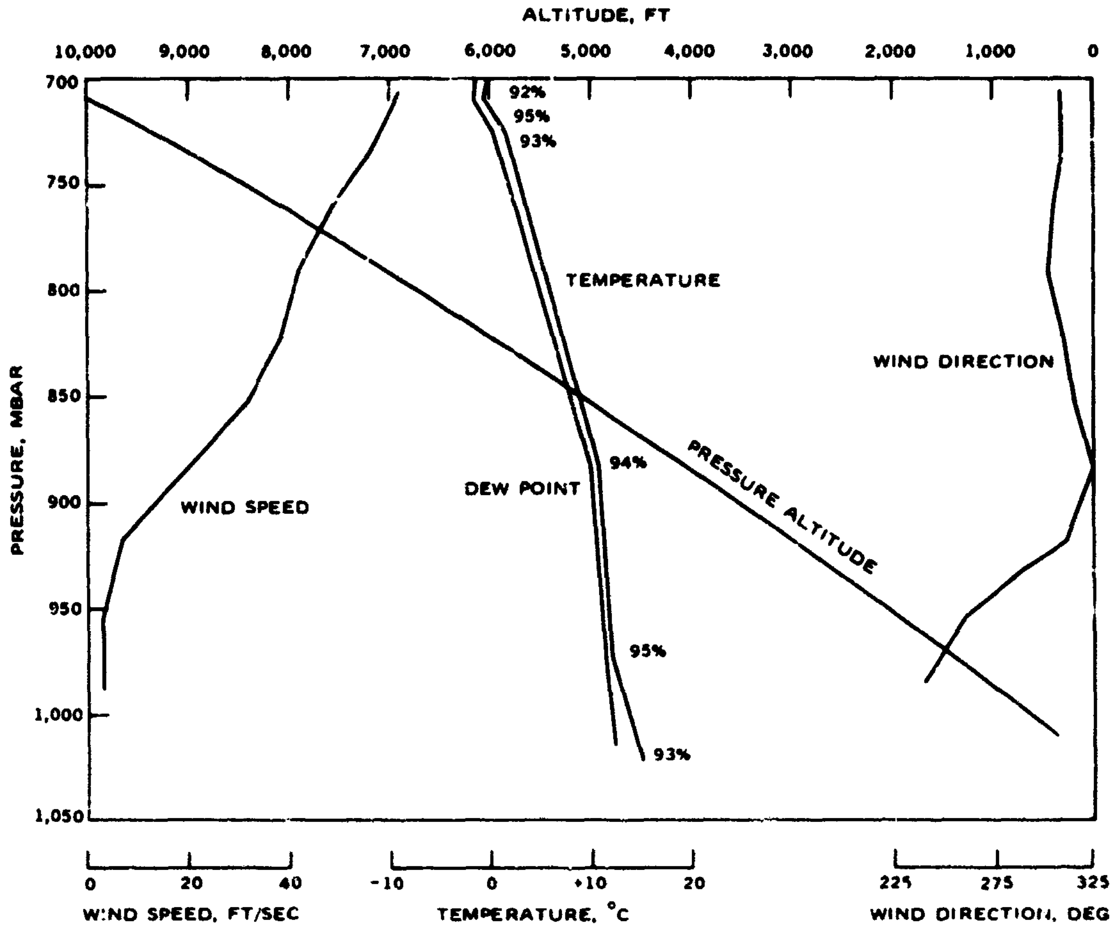


FIG. 32. Rawinsonde Data, Test 71.

2 hours, although there were short periods of great variability.

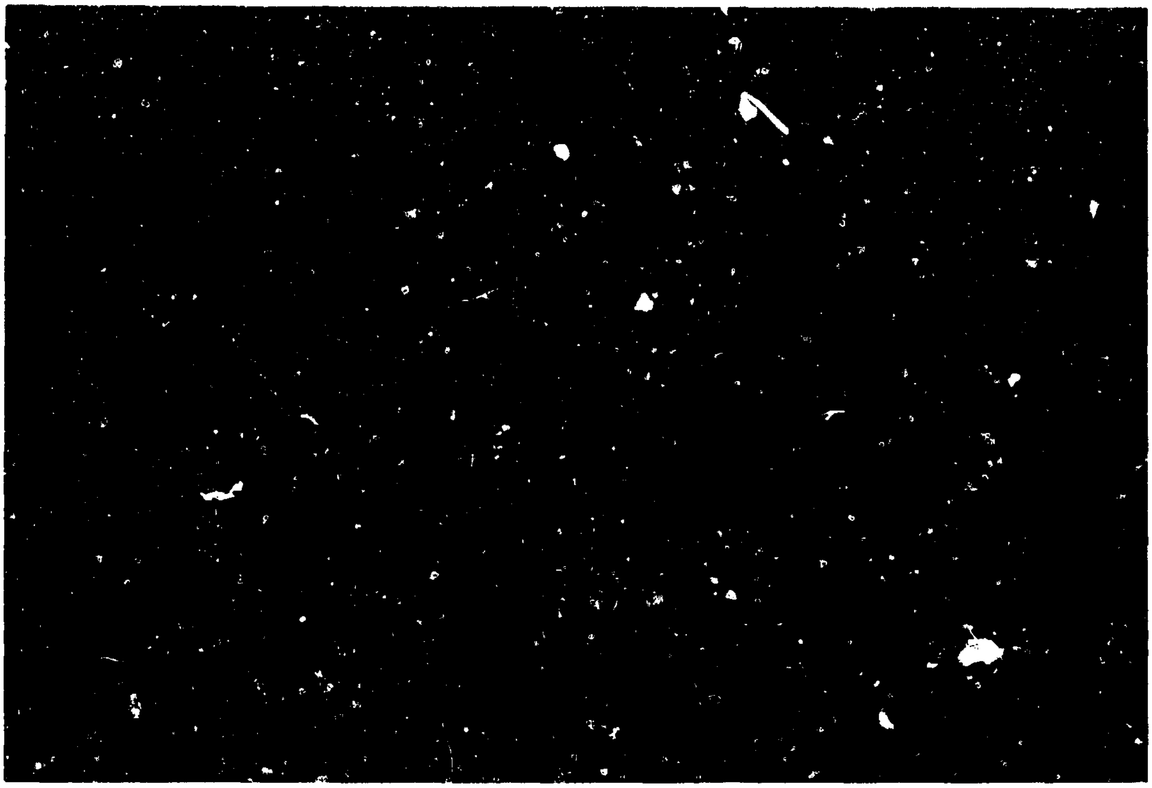
c. Rawinsonde: The information given in the 0645 sounding is shown in Fig. 32. There is a lack of detail evident in the area of interest, up to fog tops at 1,200 feet MSL.

d. Special Ground Stations: Ground observers noted that surface visibility was down, but gradually improved after seeding, with brightening of the sky overhead. Precipitation from solution droplets was felt. The taxiway in front of the tower became visible first, and then the runways. A series of photographs (Fig. 33), taken from the tower, shows the changes during the test. The seeder aircraft could be observed on their passes.

3. Aircraft Data

a. Aerial Photographs: This test was the most spectacular from the photographic viewpoint. In the T-11 camera photographs the airport and runway 31 are clearly seen through the holes that developed subsequent to seeding (Fig. 34). Color slides were taken with a hand-held Leica camera, and 16-mm movies show the development of the opening. The photographic aircraft flew at mid-altitudes, because of the interference of clouds lying at the higher levels that the aircraft normally used.

b. Visual Observations: Aircraft observers noted that the seeding track was clearly visible, had a wispy appearance, and was raised with respect to fog tops. A line of weakness with several holes developed at a small angle to the seeded track, extending from a ridge east of the airport to the coast west of the airport. Several observers saw the ground, runway, airport parking



(a)

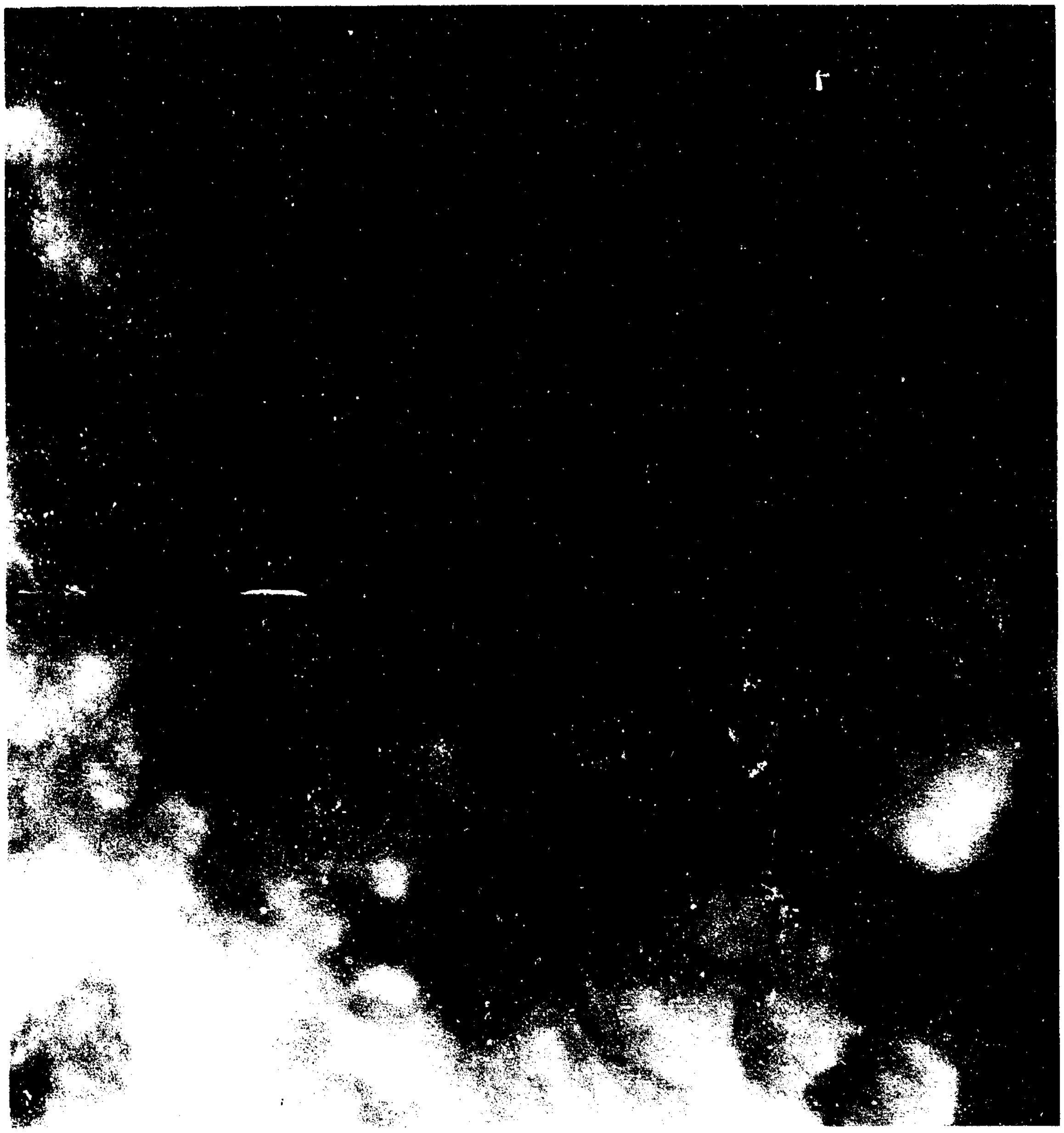
(b)

FIG. 33. Development of Visibility on the Ground During Test 71. Elapsed time between (a) and (d) about 1 hour.

(c)

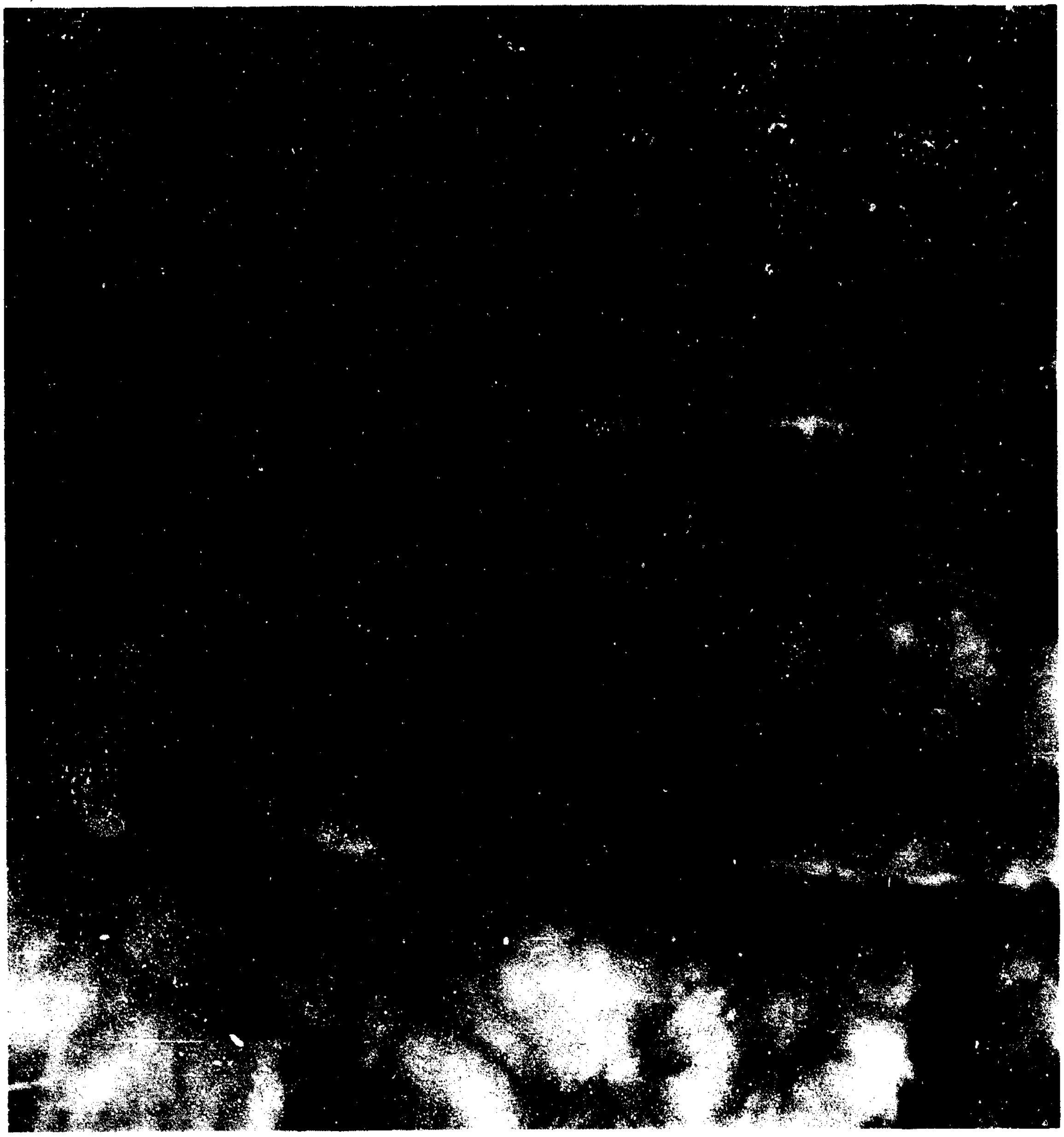
(d)

FIG. 33. (Contd.)



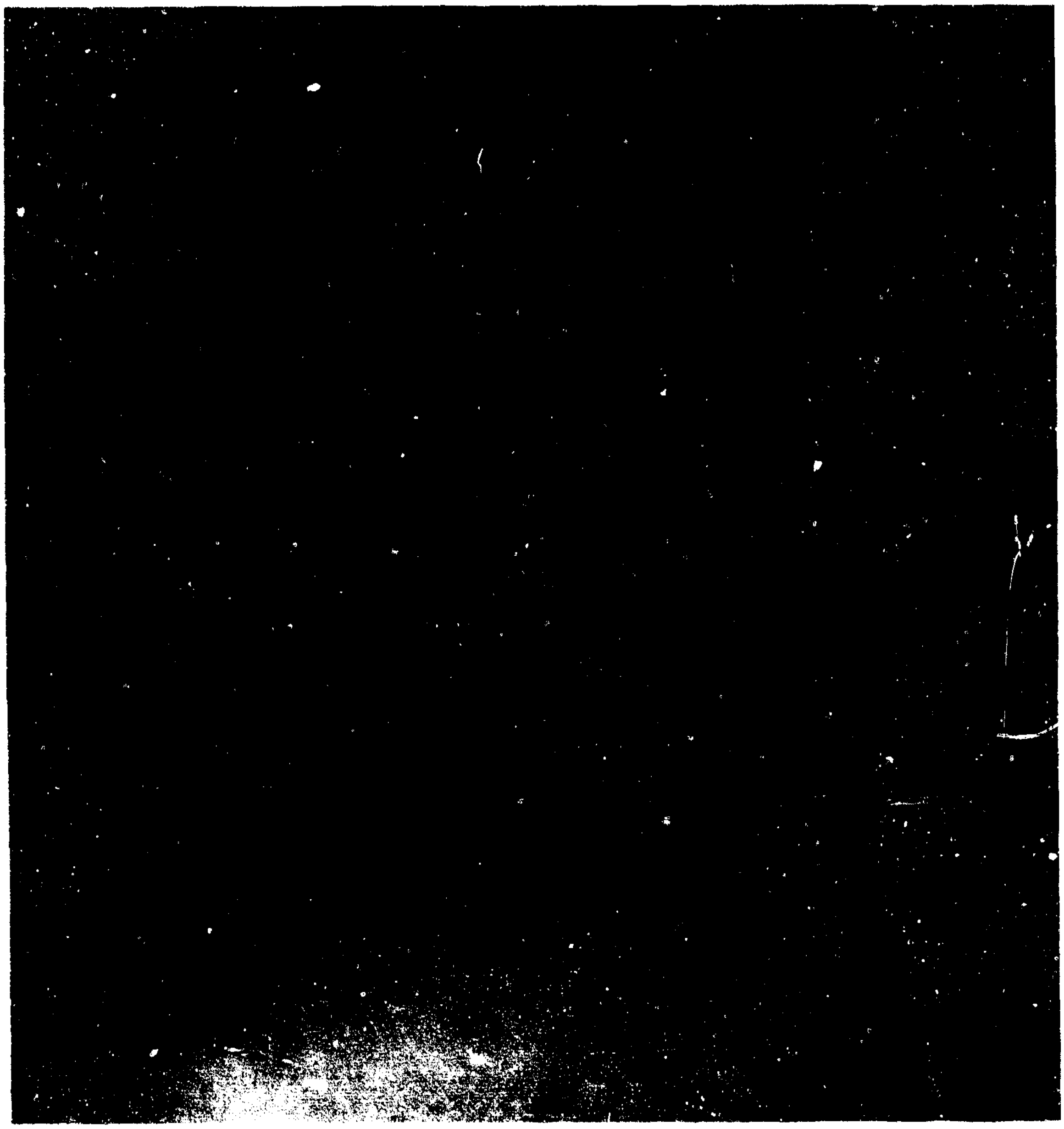
(a) Before seeding (0756).

FIG. 34. Seeding, Test 71.



(b) Seeding trails (0800).

FIG. 34. (Contd.)



(c) Control aircraft (0829).

FIG. 34. (Contd.)

(d) Hole with runway visible (0835).

FIG. 34. (Contd.)

lot, and beach. The holes closed about 45 to 55 minutes after start of seeding.

c. Minilab Data: The most notable change in the Minilab data between preseed and postseed conditions was in the liquid water content. The values were about 0.2 to 0.3 g/m^3 and declined to less than 0.1 g/m^3, with areas of precipitation evident in the postseed passes. The dew point sensor was not working during this test. Aircraft traffic interfered with obtaining postseed passes.

d. Drop Size and Distribution: The droplets at the three ground stations showed an increase in sizes and density after seeding, which tended to return to normal during the hold, then increased again during the second seeding period before returning to normal again.

CONCLUSIONS AND RECOMMENDATIONS

The most encouraging finding of the project is that a solution of, by weight, 4 parts ammonium nitrate and 3 parts urea in 0.78 part of water tends to disperse warm fog and stratus and distinctly modifies small warm cumulus. The technique of spraying the solution into the tops of warm fog gave operationally useful clearings in three tests, although other tests with the same material and similar amounts and techniques yielded less dramatic results.

The parameters have not yet been optimized with respect to material formulation and amounts, spray size, and flight parameters. Consequently, the technique is not yet considered completely reliable in terms of either predictable results in fog with a single treatment method or of having specified a set of parameters from which to select the exact method to clear fog reliably. It is believed that the thicker and wetter the cloud or fog and the greater the speed of the in-cloud wind, the more material will be required.

Test results indicate that the combination of urea and ammonium nitrate in a solids-to-water ratio of 9:1 yields a solution that is more effective than saturated solutions of the following single components: ammonium nitrate, urea, sodium chloride, and calcium chloride. Water alone produces virtually no effect.

More research is needed to obtain an optimized, reliable dispersal technique for fog and stratus and to explore further the effects produced by the material in warm cumulus.

The ammonium nitrate/urea/water system exhibits more solubility and hygroscopicity than either single-solute solution. It is a fertilizer and is noncorrosive to most metals, protected surfaces, and animal tissue.

The 2AL2, EW20, LW83, and WF8 airborne pyrotechnics are not effective in reasonable amounts as dispersal agents for warm fog or stratus.

The Salty Dog, Salty Frog I, Salty Frog II, and Briteye units produce definite modification in warm fog, but are not reliable dispersal agents and can at times cause intensification of fog conditions. Their cloud-forming capability should be evaluated further.

The hygroscopic powders, as a class, were not tested thoroughly enough to allow conclusive comparisons. Results to date tend to favor urea and calcium chloride. Results with calcium chloride seem to be proportional to the amount used and its level of introduction in the fog. In future work, test amounts of a ton or more should be evaluated. While single tests of certain kinds of powdered sodium chloride appeared promising, this chemical has been and is being tested by other agencies and should not be further explored by NWC in the next project.

Future developmental work should concentrate on no more than three or four kinds of promising seeding agents so that more tests can be devoted to such materials under a variety of test conditions.

Ground-based seeding from a single, stationary device does not appear promising with available equipment. The capability to dispense material in sufficient amounts for operational clearing may require roughly 10 such units for adequate horizontal coverage, and an increase of 50% or so in the height to which seeding agents can be dispensed by each unit of the two types of vertical-wind machines tested.

The spray-system nozzles tested produce similar and broad spectra of spray-droplet sizes that may be too large for most efficient use of seeding solutions. Nozzles or spray techniques that give droplets whose highest frequency of sizes lies below 100 microns should be tested.

Data-gathering and -handling techniques used in Foggy Cloud I were generally successful but could be improved in the following ways:

1. The Minilab data-reduction process should be automated as fully as possible.

2. A drop-size measuring capability for in-cloud sampling should be perfected.

3. A plume-tracking method, or methods, sensitive to each seeding material, should be developed.

4. Simple devices, capable of sensing the seeding agent being tested, should be developed for placement in a network on the ground. This procedure would allow mapping the position of the treated volume with respect to surface-based observations.

5. Laboratory work should be conducted to relate the crater diameter on gelatin-coated slides to the true diameter of the settling droplets replicated thereon.

The Arcata-Eureka airport is an excellent base location for warm-fog studies. The incidence of test weather is high, special facilities and equipment are available, and the cooperation of local officials is outstanding.

Subject to security needs, NWC should continue its policy of open exchange of information with other U.S. agencies conducting warm-fog research. Classification of test data and results tends to inhibit profitable cooperative work and should be held to a minimum necessary to best serve national interests.

REFERENCES

1. Houghton, H. G., and W. H. Radford. "On the Local Dissipation of Natural Fog," in *Papers in Physical Oceanography and Meteorology*, Vol. 6, No. 3. Cambridge and Woods Hole, Mass., Massachusetts Institute of Technology and Woods Hole Oceanographic Institute, October 1938.
2. Junge, C. E. "Methods of Artificial Fog Dispersal and Their Evaluation," Air Force Surveys in Geophysics, No. 105, Bedford, Mass., September 1958.
3. Headquarters Air Weather Service (VPS). *A Summary of Field Activities Conducted Under USAF Directive Combat Warm, Final Report*. Scott Air Force Base, Ill., March 1969.
4. Cornell Aeronautical Laboratory. *Project Fog Drops*, by W. C. Kocmond. Buffalo, N.Y., CAL, February 1969. (CAL Quarterly Report RM-1788-P-22.)
5. National Bureau of Standards. *A Summary of Low Visibility Conditions at the Arcata Airport*, by James E. Davis, J. W. Simeroth, and J. C. Wilkerson. Washington, D.C., NBS, November 1968. (NBS Report 9958.)
6. Morton, B. R., Sir Jeoffrey Taylor, and J. S. Turner. "Turbulent Gravitational Convection from Maintained and Instantaneous Sources," ROY SOC LONDON, PROC A, Vol. 234 (1956), pp. 1-23.
7. Naval Weapons Center. *A Research Study Directed Toward Developing a Scheme for Meteorological Sensing, in Real Time From an Aircraft, of Water Droplet and Ice Crystal Sizes and Distributions in Clouds*, by John G. Ballinger, Willard E. Anderson, Hans W. Mocker, and Eric K. Jaede. China Lake, Calif., NWC, September 1969. 388 pp. (NWC TP 4789.)

Appendix A

CALCULATIONS AND ANALYSIS OF PLUME RISE

Two seeding tests are described here in which an attempt was made to determine the contribution of the heat of condensation to the plume rise observed in the tests with ground-burned pyrotechnics. A search was made of the literature to get a mathematical model for computing the predicted plume rise from the heat of combustion of the pyrotechnic units burned. By comparing the observed plume rise with the computed plume rise, it was hoped to obtain the amount of heat of condensation due to the difference. The results were disappointing, probably because of violations of the basic assumptions.

Analysis of Plume Rise for Extra Test, 30 July

Analysis Scheme. Morton (Ref. 6) developed an equation to predict the height attained by a plume of air or smoke above a heat source at the surface:

$$H = 31\ (1 + n)^{-3/8} Q^{1/4} \qquad (1)$$

where H is the height in meters, 31 is a constant containing appropriate units, and n is the ratio of $\Delta T/L$; ΔT is the temperature at the top of the layer minus the temperature at the base of the layer, divided by the thickness in kilometers. For inversion conditions, n is positive because L (the dry adiabatic lapse rate, 9.8°C/km) is taken as *positive* by convention. Q is the heat-source production rate, measured in kilowatts.

Experimental Conditions. Two assumptions of the above equation were not met by the actual test conditions. These entail assuming (1) a constant nonsuperadiabatic lapse rate throughout the layer of air containing the plume and (2) still air. In the test the following temperatures were observed:

Surface to 303 feet: −1.9°C

303 to 1,123 feet: +4.3°C (or +17.2°C/km)

Since the lower layer had a superadiabatic lapse rate, the equation does not fit. Hence, a calculation was made of the rise predicted for the layer above 303 feet.

For the cluster of three Salty Frog CY-91 units, the total heat of combustion was released in 5 minutes, giving a value for Q of 1,250 kilowatts.

Under these conditions, H is computed to be 425 feet above the 303-foot starting point, or 728 feet AGL. The observed plume was 643 feet AGL (860 feet MSL).

The discrepancy between the predicted plume height and the observed plume height is in the direction qualitatively predicted in view of the 5- to 6-knot surface wind. Another factor that would tend to explain the discrepancy is that the plume materials may have extended somewhat above their visible top. A third factor that would inhibit the plume height is that the CY-91 units are not giving complete combustion. Thus, the value for Q used in the equation is probably too large, being derived from laboratory measurements with complete combustion. Opposing this factor, however, is the heat gained by slight condensation (relative humidity = 80%) during this experiment.

The overall conclusions are

1. The experimental conditions were far from ideal for this test.
2. In spite of this, the equation gives a "ball-park" estimate of the plume top.
3. The difference between the theoretical and actual plume height is in the right direction, considering the existing wind and other conditions.

Analysis of Plume Rise in Test 37, 15 August

Analysis Scheme. Test 37 was run as a seeding test, using three clusters of three Salty Frog CY-91 units. The height attained by the plume was computed by Eq. 1, as was done in a similar analysis of the extra test on 30 July.

Experimental Conditions. Unfortunately, as in the earlier test, the conditions of the equation were not met, although different assumptions were violated this time. During this test, the requirements for still air and for a constant, nonsuperadiabatic lapse rate were reasonably well met. However, since Test 37 was conducted as a seeding test, fog was present up to 650 feet MSL. Therefore, parcels of air moving upward would do so moist adiabatically and not dry adiabatically as the equation assumes. This means that the parcels of air in reality were warmer and hence more buoyant than is assumed in the equation, which by this argument should *underpredict* the final plume height. This was not the case, as will be shown later.

In Test 37, the total burning time was 10 minutes, 40 seconds from the sequential firing. The lapse rate was constant over the height of the plume, and was 5.9°C/km. These data give a predicted plume height of 555 AGL. The plume height, as observed visually from the Minilab aircraft, was 483 feet AGL.

DISCUSSION

Fog occurred to within about 50 feet of the top of the plume. Therefore, there was undoubtedly some condensation occurring on the hygroscopic nuclei produced by the Salty Frog units. If this condensation were sufficient to exhaust the fog droplets and some additional vapor from the air, the latent heat of such vapor condensation would enhance the plume growth. Probably most of this condensation would occur near the burning site, so that the heat would be additive to the Q term in Morton's equation. Unfortunately, Morton's equation is not sensitive to changes in Q because of the fourth root effect. That is, an order of magnitude increase in Q would yield only a 17.8% increase in H; nonetheless, if Morton's equation applies well, and if the experimental data are accurate, then the plume height result should allow an estimate of the amount of additional heat realized by the condensation of water vapor. In equation form

$$H_{observed} = f\left(Q_{combustion} + Q_{condensation}\right) \qquad (2)$$

Because the predicted value of H in this experiment, based on heat of combustion alone, exceeded the observed value, one can say only that either there are flaws in the equation and/or data, or that the plume realized little or no *net* heat of condensation. Because the predicted value and the observed value for H are in fair agreement in this test and in the 30 July test, and because visual observations do not indicate a depletion of fog droplets, it is concluded that most or all of the plume rise is due to the heat of combustion.

Appendix B

CORNELL AERONAUTICAL LABORATORY REPORT RM-1788-P-21

We appreciate the careful work done by CAL and reproduced here in facsimile. Their cooperation was solicited in informal discussions in June 1968. CAL has been most helpful in sharing all its pertinent research findings with us, as well as with other agencies interested in the dispersal of warm fog.

One advantage of fog-chamber testing is that the investigator can to a large degree hold constant from test to test the important properties of fogs being seeded, a capability that does not generally exist in field experiments. This control over fog properties allows a more meaningful comparison of various seeding agents. One fundamental limitation of fog-chamber testing is that the conclusions are only as applicable to the real atmosphere as the degree to which the model fog represents natural fog. This notion is well appreciated by Mr. Kocmond; his discussions (pp. B-8 and B-15) are stated to pertain to "laboratory fog."

The data of their Table I (p. B-6) show that the CAL laboratory fogs are in many ways similar to natural radiation fogs. The most striking difference is in the limited depth of the chamber fogs, of course owing to the cost and inconvenience that a very tall chamber would entail. The implications of this modeling limitation for extrapolating to results in seeding deep natural fog are largely unknown.

Mr. Kocmond points out that the droplet size spectrum of the seeding solution spray was not optimized (p. B-7) for tests in the chamber. The stated drop-size distribution in these tests (Fig. 2 of CAL report) is much narrower and represents about an order of magnitude smaller droplets than those used in our field tests in Project Foggy Cloud I. The effect of spray drop-size spectra on seeding results will be studied in future projects.

Our comments, above, were checked for technical accuracy during a telephone conversation with Mr. Kocmond.

CORNELL AERONAUTICAL LABORATORY, INC.
BUFFALO, NEW YORK 14221

PROJECT FOG DROPS

PROGRESS REPORT: EVALUATION OF THE EFFECT OF AN AMMONIUM NITRATE•UREA•WATER SOLUTION ON DENSE LABORATORY FOG

CONTRACT No. NASr-156
CAL REPORT No. RM-1788-P-21

NOVEMBER 22, 1968

PREPARED BY: Warren C. Kocmond
Warren C. Kocmond
Project Engineer

APPROVED BY:
Roland J. Pi[illegible], Asst. Head
Applied Physics Department

LABORATORY FOG SEEDING EXPERIMENTS

Cornell Aeronautical Laboratory Inc., under sponsorship of the Aeronautical Vehicles Division of NASA (Contract NASr-156), has agreed to perform a series of laboratory evaluations of several fog seeding chemicals provided by the Naval Weapons Center, China Lake, California. This report summarizes preliminary results obtained from experiments in which prepared solutions of ammonium nitrate • urea • water were injected into dense laboratory fogs. The relative proportions, by weight, of reagents used in preparing the seeding material were: 4 parts NH_4NO_3, 3 parts urea, and 0.78 parts distilled water (i.e., 9 parts of reagent to 1 part of water).

A. EQUIPMENT

Fogs were produced in the CAL Ordnance Laboratory located at Ashford, N.Y. The facility, pictured in Figure 1, consists of a cylindrical chamber which can be pressurized or evacuated at controlled rates. In essence, adiabatic expansions are produced, and under appropriate initial humidity conditions, fogs form. These laboratory fogs were found to possess liquid water contents and drop-size distributions that are representative of natural inland fogs.

The cloud chamber is 30 ft. in diameter and 30 ft. high, enclosing a volume of approximately 600 m^3. Construction material consists of 0.5 inch sheet steel with an epoxied inner surface. As shown, a rotating spray nozzle enables the walls and floor of the chamber to be thoroughly wetted with water, and the relative humidity of the air to approach 100%. Glass ports are located at various levels for monitoring the fog visually or with transmissometers.

By means of a blower-circulation system, the chamber can be pressurized to approximately 20 cm of water. After permitting the internal temperature and humidity to equilibrate with the wet walls, the chamber can then be vented to the outside at controlled rates. Adiabatic expansions are thereby produced. To maintain fog for extended periods, air can be vacuum-pumped out of the large chamber at controlled rates to produce a continuous, slow expansion. In this way, representative fogs can be formed for subsequent seeding experiments. Moreover, fog visibility can be held essentially constant by controlling the secondary expansion.

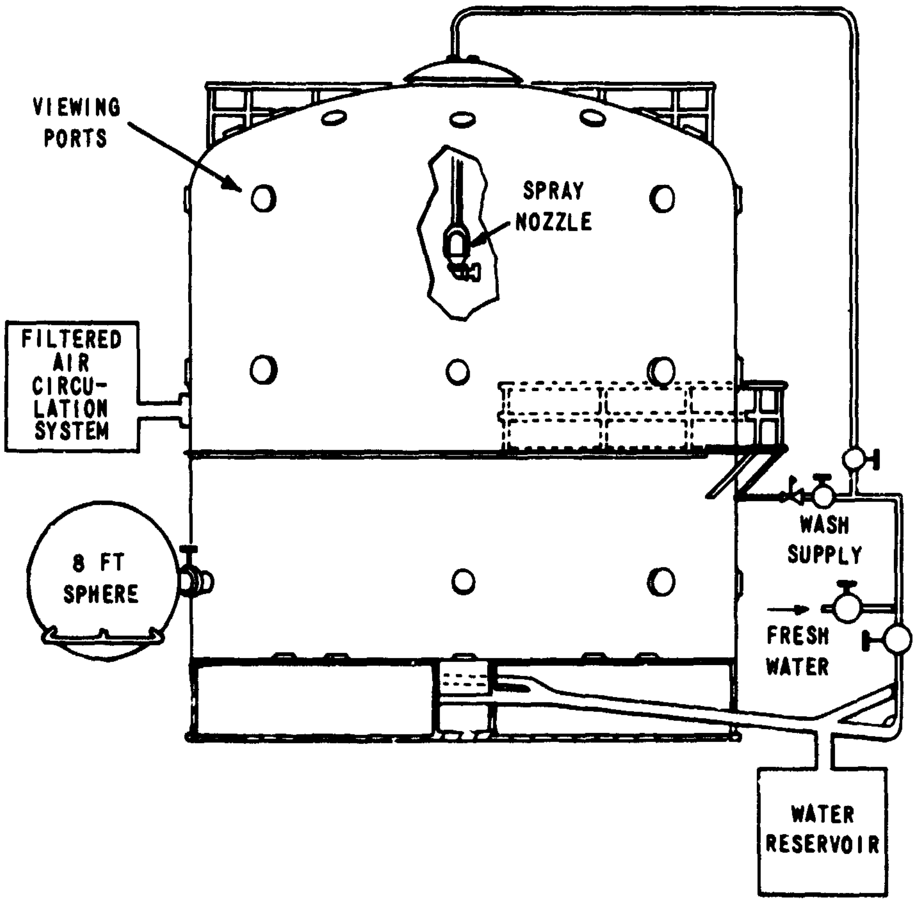


Figure 1 THE 600m^3 TEST CHAMBER AT ASHFORD, NEW YORK

In a typical experiment the procedure used in evaluating the candidate seeding material was to produce one fog for use as a control and observe its physical characteristics as a function of time. A second fog was then produced and seeded with a predetermined amount of NH_4NO_3 · urea · water solution (hereafter referred to as the 9:1 solution). After the initial fog forming expansion, in both seeded and control fogs, a continuous, slow secondary expansion was initiated in order to cause the fog to persist.

Typical physical characteristics of the laboratory fogs approximately one minute after completion of the initial fog forming expansion are compared in Table I with the radiation fog model developed earlier on Project Fog Drops (NASA Contract NASr-156). It is apparent that the similarities are excellent.

TABLE I

Characteristics of Laboratory Fog and Natural Radiation Fog

Fog Parameter	Laboratory Fog	Natural Radiation Fog
average drop radius	4 to 5μ	5μ
typical drop radius range	2 - 18 to 2 - 22μ	2 - 18μ
liquid water content	150 to 200 mg m^{-3}	110 mg m^{-3}
droplet concentration	250 to 500 cm^{-3}	200 cm^{-3}
visibility	200 to 400 ft.	300 to 900 ft.
vertical depth	10 m	100 to 300 m

The primary sensors used to monitor fog characteristics within the chamber are outlined below:

1. Two transmissometers for recording horizontal visibility (i.e. extinction coefficient) over a 60 ft. path (30' baseline with reflecting mirror). One transmissometer was located at a level of 4 ft. and the second at 15 ft.

2. A fog-droplet sampler, employing a gelatin replication technique, for measuring drop-size distributions at selected times during the fog's life cycle.

3. Psychrometric equipment for estimating relative humidity (at the lower level only).

Transmissometer data were recorded externally, while other equipment was manually operated from within the chamber. Visual observation, by the operator, of fog characteristics and seeding plume added substantially to the experiments.

Seeding nuclei (droplets) were injected into the fog by a droplet disseminator located approximately 25 feet above the chamber floor. The apparatus was capable of disseminating the prepared solution into the fog at a rate of ~3 gm/min. Drop size distributions of water droplets and of solution droplets produced by this equipment are shown in Figure 2.

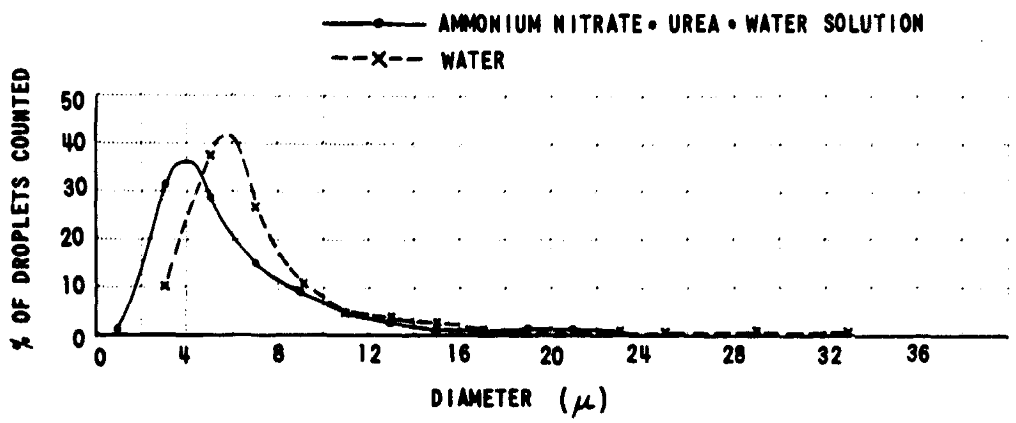


Figure 2 DROP SIZE DISTRIBUTIONS PRODUCED BY PARTICLE DISSEMINATOR USED IN SEEDING EXPERIMENTS

B. SUMMARY OF RESULTS

The primary objectives of the seeding experiments at Ashford, N.Y. were (1) to determine the maximum improvement of visibility that could be achieved by seeding with the ammonium nitrate • urea • water solutions and (2) to compare these results with data obtained from seeding experiments using NaCl particles of carefully controlled size. It must be noted, here, that the optimum droplet sizes required to effect laboratory fog dissipation have not yet been established for the 9:1 solution. Once these calculations are made it may be possible to seed with drop sizes that are more effective in causing dissipation of fog. An urgency to perform preliminary laboratory tests, however, precluded detailed investigation of optimum droplet sizes as well as development of the necessary seeding equipment. Nonetheless, results of these experiments have demonstrated that visibility in laboratory fog can be improved by a factor of at least two and as much as six by seeding with the 9:1 solution. In our tests the minimum amount of material required to effect a significant visibility improvement (factor of 2 over the control fog) exceeded 10 mg of solution per cubic meter of foggy air. By comparison, equivalent improvements in visibility were achieved with as little as 2.5 mg of carefully sized NaCl per cubic meter of fog.

Table II summarizes the maximum visibility improvements (seeded fog relative to control fog) achieved in the current experiments. Results from previous tests in which sized dry NaCl particles were used are also tabulated.

The data in Table II suggest that both NaCl and urea particles of controlled sizes are more effective in clearing laboratory fog than the 9:1 solution seedings. Before this hypothesis can be verified, however, it will be necessary to perform tests using optimum solution droplet sizes during seeding. These tests will be conducted during the next three months.

In Figures 3, 4, and 5 transmissometer data at two levels in the fog chamber are shown for control fogs and fogs seeded with 30 gm, 15 gm, and 6 gm of the 9:1 solution (50 mg/m^3, 25 mg/m^3, 10 mg/m^3 respectively). Control fogs were seeded with approximately 45 gm of water to determine if any noticeable change in visibility was produced by water seeding. The effect was negligible when compared with other unseeded control fogs.

It is apparent from these data that the 30 gm and 15 gm seedings were effective in producing substantial improvement in fog visibility (visibility improvement factor of 6.1 and 4.7 respectively). The 6 gm seeding, on the other hand, produced only marginal results.

In Figure 6, four selected drop size distributions are shown at various times for the control fog and the fog seeded with 30 gm of 9:1 solution. The

Table II
VISIBILITY IMPROVEMENT FACTORS* FOR SEEDING EXPERIMENTS IN $600 m^3$ CLOUD CHAMBER

SEEDING MASS AND MODAL DIAMETER OF PARTICLE DISTRIBUTION	VISIBILITY AT TIME OF SECONDARY EXPANSION	MAXIMUM VISIBILITY IMPROVEMENT FACTOR
2.5 gm NaCl (4μ)	SEEDED 280 FT CONTROL 180	2.8
5 gm NaCl (4μ)	SEEDED 270 FT CONTROL 280	4.0
5 gm NaCl (4μ)	SEEDED 210 FT CONTROL 160	7.5
5 gm NaCl (8μ)	SEEDED 210 FT CONTROL 230	6.2
5 gm UREA	SEEDED 150 FT CONTROL 155	6.6
6 gm NH_4NO_3•UREA•WATER (4μ)	SEEDED 110 FT CONTROL 110	1.5
10 gm NaCl (4μ)	SEEDED 210 FT CONTROL 180	13.2
10 gm NaCl (8μ)	SEEDED 255 FT CONTROL 185	9.9
10 gm UREA	SEEDED 230 FT CONTROL 230 FT	8.3
15 gm NH_4NO_3•UREA•WATER (4μ)	SEEDED 150 FT CONTROL 110	4.7
30 gm NH_4NO_3•UREA•WATER (4μ)	SEEDED 130 FT CONTROL 110	6.1

*VISIBILITY IMPROVEMENT FACTOR IS DEFINED AS THE RATIO OF THE VISIBILITY OF THE SEEDED FOG TO THE VISIBILITY OF THE CONTROL FOG AT THE SAME TIME AFTER INITIATION OF THE EXPANSION

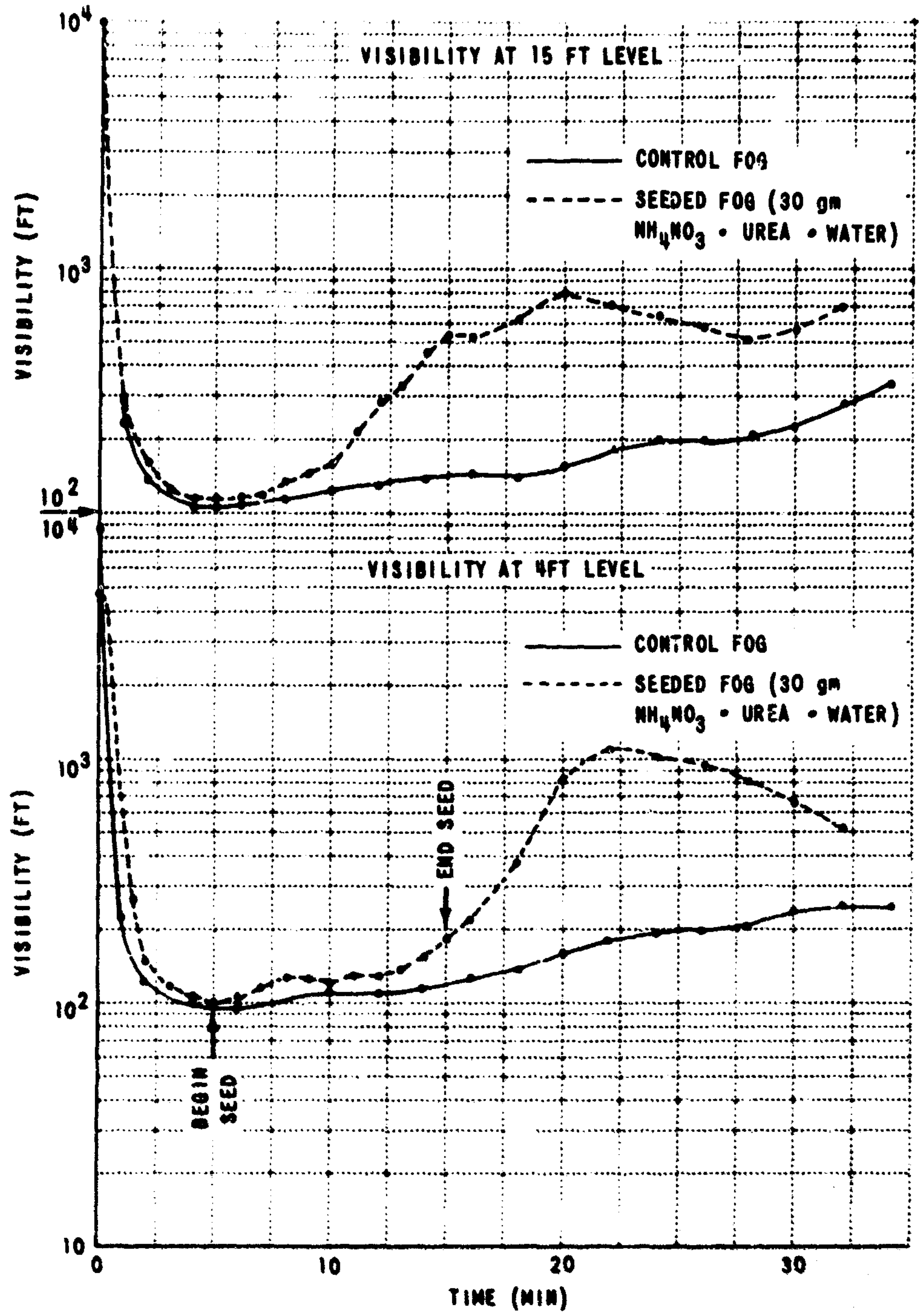


Figure 3 VISIBILITY AS A FUNCTION OF TIME FOR A SEEDED AND CONTROL FOG

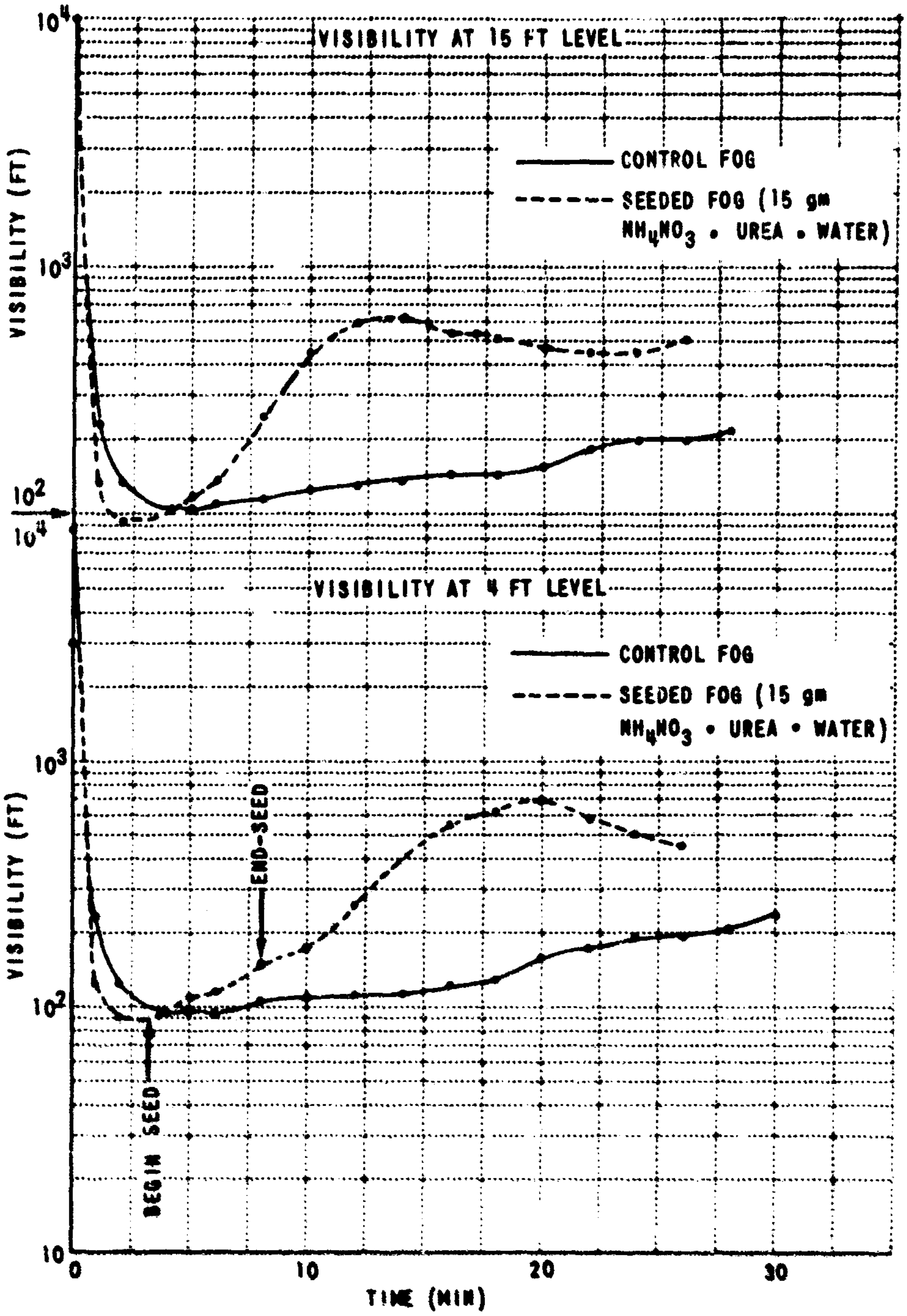


Figure 4 VISIBILITY AS A FUNCTION OF TIME FOR A SEEDED AND CONTROL FOG

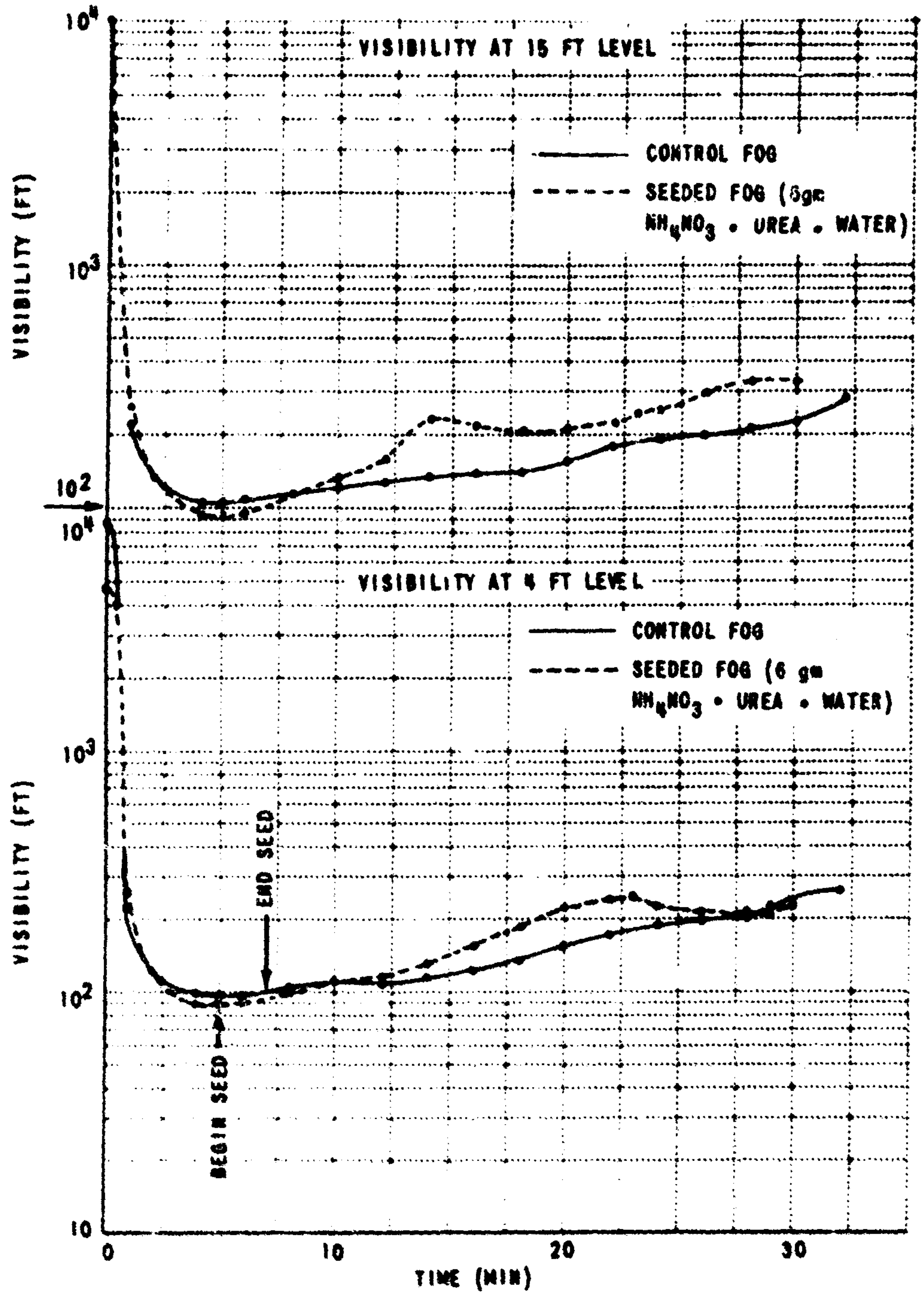


Figure 5 VISIBILITY AS A FUNCTION OF TIME FOR A SEEDED AND CONTROL FOG

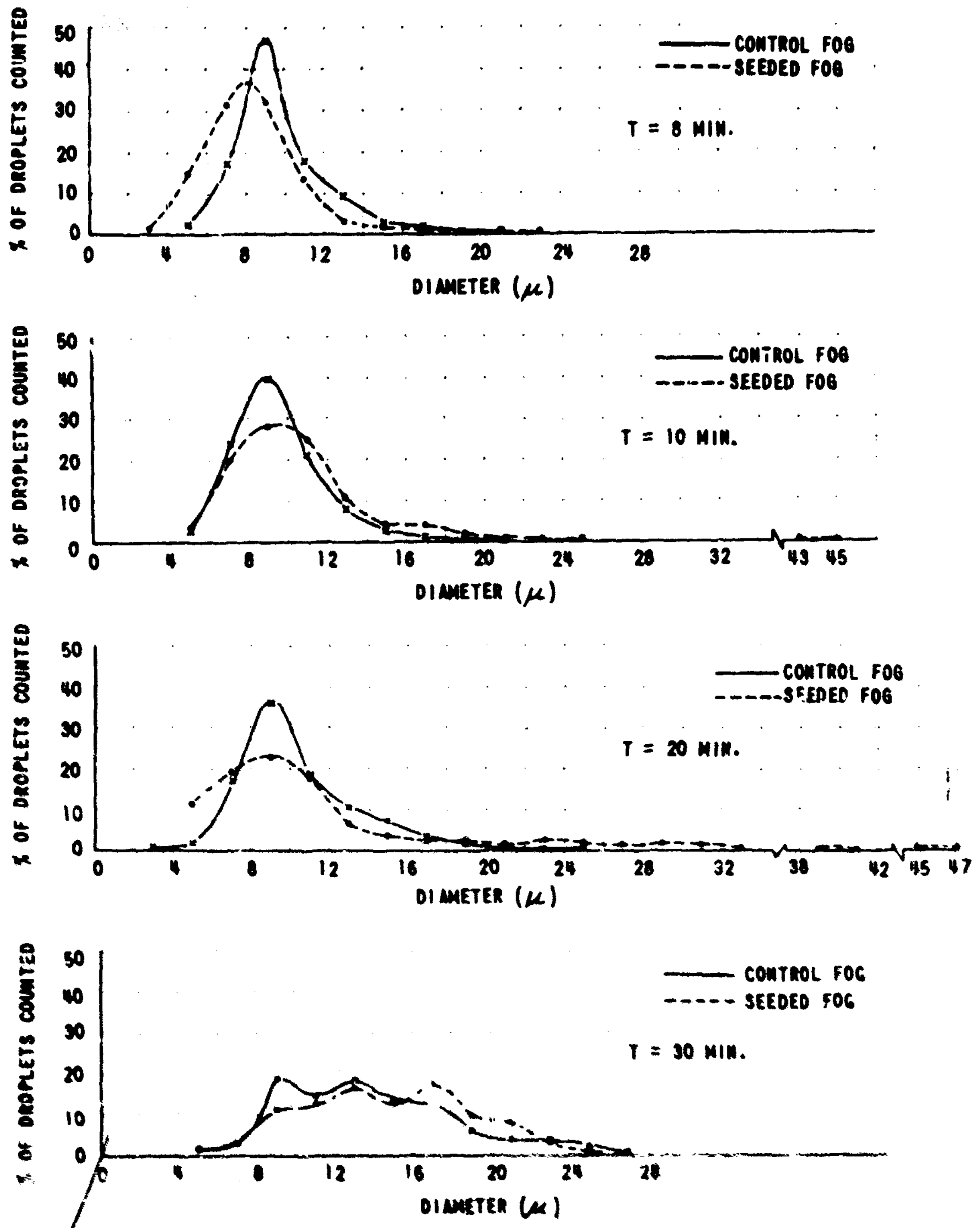


Figure 6 DROP SIZE DISTRIBUTIONS FOR SEEDED AND UNSEEDED FOGS AT THE INDICATED TIMES FROM START OF EXPERIMENT. SEEDING ACCOMPLISHED WITH 30 gm NH_4NO_3 · UREA · WATER SOLUTION

distributions correspond to times T = 8 min., 10 min., 20 min., and 30 min. from the start of the experiment. Seeding was started at T = 5 min. and lasted for 10 min. Note from the figure that at T = 8 min., the drop size distributions are very nearly the same for both the seeded and control fog. At T = 10 min., a few significantly larger drops appear in the seeded fog. These drops, of course, are the result of seeding and were produced through diffusional growth on solution droplets disseminated into the fog (recall from Figure 1 that the largest drops produced by the particle disseminator were about 23μ diameter, whereas in the figure droplets of 45μ are evident). By T = 20 min., significant redistribution of drop sizes has occurred in the seeded fog. It is likely that at this time most of the liquid water in the fog is accounted for by the few very large drops shown in the distribution (when data analysis is complete, the improvements in visibility due to changes in liquid water content and to drop size distribution will be compared.) At T = 30 min., the drop size distributions are similar for both the seeded and control fogs. By this time most of the larger droplets that grew on the artificial nuclei have settled out of the fog. In the control fog, continued growth of natural droplets has produced a fairly broad spectrum of drop sizes. The end result is that the droplet spectra for both fogs are nearly alike at the completion of the experiment.

C. DISCUSSION OF RESULTS

From previous laboratory fog seeding experiments it has been found that two processes are responsible for producing the visibility improvements after seeding. Initially, improvement in visibility results from a favorable shift in the drop size distribution from one consisting of a large concentration of small droplets to one containing a few larger drops. Accompanying the change in drop sizes is a decrease in the amount of scattered light (extinction coefficient) and hence an increase in visibility. At first, only slight changes occur in the liquid water content of the fog. As time progresses however, precipitation of droplets in the seeded fog causes a reduction in the liquid water content of the fog and further improvements in visibility.

If it is assumed that the hygroscopic nature of the ammonium nitrate • urea • water solution is responsible for clearing fog then it is reasonable to suggest that processes similar to those just described are responsible for the manner in which visibility improves. In spite of significant visibility improvements however, the 9:1 solution did not appear to be as effective in clearing laboratory fog as the carefully sized dry particles of NaCl or urea. Calculations will be made to determine the optimum particle sizes needed for effective fog dissipation and additional laboratory experiments will be performed to establish the lower limit of solution seeding material needed. At that time conclusions can be drawn relative to the effectiveness of the solution vs. dry NaCl particles.

Appendix C

DATA ON THE SYSTEM AMMONIUM NITRATE/UREA/WATER

by Lohr A. Burkardt

The data reported here represent an effort to supply reasonably accurate information on the ammonium nitrate/urea/water system to meet the immediate needs of field experiments. If the results of field tests are encouraging, it is planned to study this system with the aim of obtaining data with a high degree of precision. Except where stated otherwise, the solutions were prepared from chemically pure ammonium nitrate (Baker's analyzed), chemically pure urea (Baker and Adamson), and distilled water. Weighings of the solution components were made on a large analytical balance (1-milligram sensitivity).

SOLUBILITY DETERMINATIONS

Method

Approximately 150 milliliters of a solution under test was placed in a small beaker held in a water bath. The sample was vigorously stirred while the temperature of the bath was slowly lowered by the addition of ice water. The temperature of the sample was continuously monitored by recording the output of a Chromel/Alumel thermocouple on an X/Y recorder. The thermocouple had been calibrated against a quartz thermometer. Precipitation of solids from solution was indicated by a plateau or rise in the sample temperature.

Results

The data obtained for compositions in which the number of moles of ammonium nitrate and urea per mole of water was varied but the number of moles of ammonium nitrate was kept equal to the number of moles of urea are shown in Table C-1 and Fig. C-1. With these compositions, precipitation occurs in two stages. An X-ray diffraction pattern of material precipitated in the first stage showed this to be ammonium nitrate. An X-ray diffraction pattern of material from the second stage of precipitation showed this to be ammonium nitrate and urea. These solutions showed a marked tendency to supercool. A better approach to determining solubility limits in this system would be by heating curves in an apparatus based on the same principle as that described by Burkardt, McEwan, and Pitman (Ref. C-1). Because of this tendency toward supercooling, the liquidus data reported here will tend to be somewhat lower than the correct values.

The two-stage precipitation noted in solutions containing ammonium nitrate and urea in a 1:1 molar relationship suggested that maximum solubility would occur in a composition containing a slight excess of urea. A few tests were made of compositions in which the ratio of urea to ammonium nitrate was varied but the total moles of urea plus ammonium nitrate per mole of water was kept constant. The results are indicated in Fig. C-2.

TABLE C-1. Data on the System Ammonium Nitrate/Urea/Water.

Part solids/ part water, wt.[a]	Composition, moles			Primary liquidus temp., °C	Secondary liquidus temp., °C	pH	Vapor pressure		Density (vacuum) at 26°C, g/ml	Viscosity at 26°C, centipoises
	Ammonium nitrate	Urea	Water				mm Hg	Temp., °C		
12.442	1.60	1.60	1.00	25.20	22.80	4.80	...	...	1.381	...
11.664	1.50	1.50	1.00	...	...	...	5.9	26.0	...	...
10.116	1.30	1.30	1.00	20.25	16.60	5.20	6.9	25.8	1.372	14.6
8.942	1.15	1.15	1.00	16.30	13.00	...	...	...	...	12.6
7.776	1.00	1.00	1.00	13.70	9.50	5.50	7.9	25.8	1.361	10.5
6.998	0.90	0.90	1.00	10.50	7.60	5.29	...	...	...	...
6.221	0.80	0.80	1.00	7.40	...	5.19	9.1	26.0	1.346	...
4.666	0.60	0.60	1.00	1.40	...	5.50	9.5	25.7	1.328	5.8
3.110	0.40	0.40	1.00	...	...	...	11.3	26.1	...	...
1.555	0.20	0.20	1.00	...	...	...	14.7	26.0	...	...

[a]Solids = 1 part urea plus 1.333 parts of ammonium nitrate by weight.

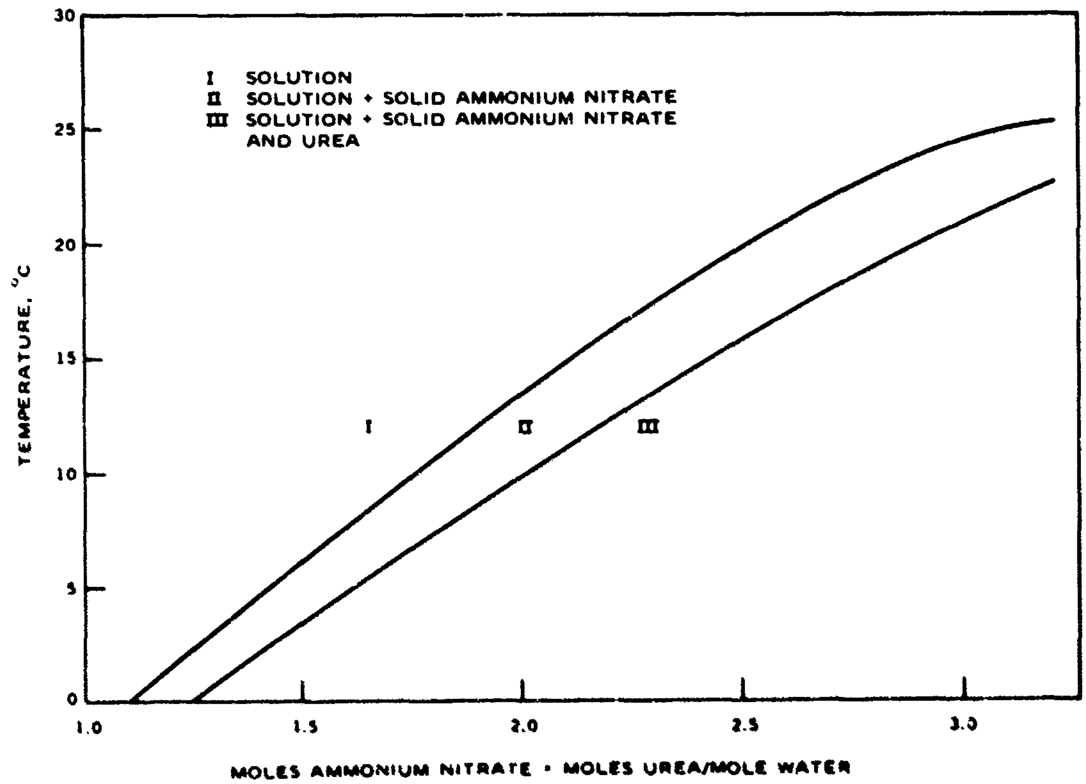


FIG. C-1. Solubility of Ammonium Nitrate/Urea/Water Solutions Where Moles of Ammonium Nitrate Equal Moles of Urea.

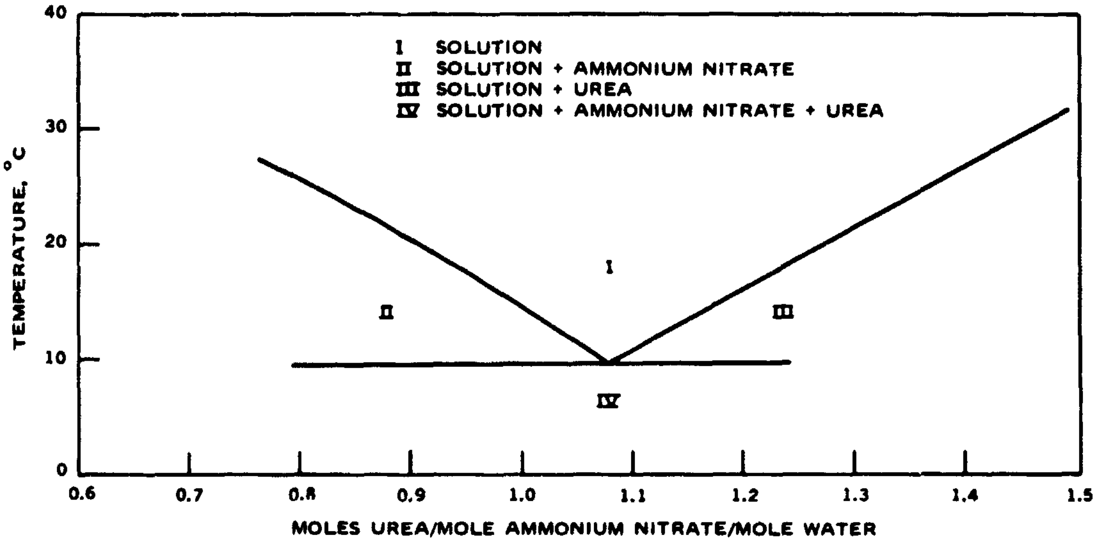


FIG. C-2. Solubility of Ammonium Nitrate/Urea/Water Solutions Where Moles of Urea Plus Moles of Ammonium Nitrate Equal Moles of Water.

pH DATA

Method

The determination of the pH of some of these solutions was made with a Beckman pH meter (glass electrode) at room temperature (26°C).

Results

The results obtained are given in Table C-1. The pH of these solutions tended to drift toward the value of 5.50 during the course of the determination.

SOLUTION DENSITIES

Method

A 25-milliliter pycnometer was calibrated at 26°C with distilled water. The solutions and pycnometer were allowed to equilibrate in the area adjacent to the balance. A thermometer was kept in the same area. All temperature readings in this area gave a constant result of 26°C.

Results

The density results, reduced to a vacuum, are tabulated in Table C-1 and shown graphically in Fig. C-3.

SOLUTION VISCOSITIES

Method

The viscosity of some of these solutions was determined at room temperature (26°C) by means of the Brookfield viscometer using the ultralow adapter.

Results

The viscosity results are tabulated in Table C-1 and shown graphically in Fig. C-4.

VAPOR PRESSURE MEASUREMENTS

Method

Vapor pressure measurements were made by

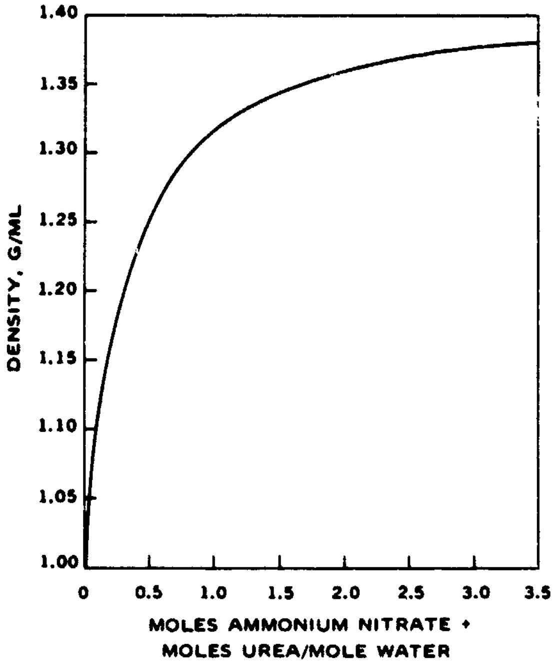


FIG. C-3. Density of Ammonium Nitrate/Urea/Water Solutions at 26°C.

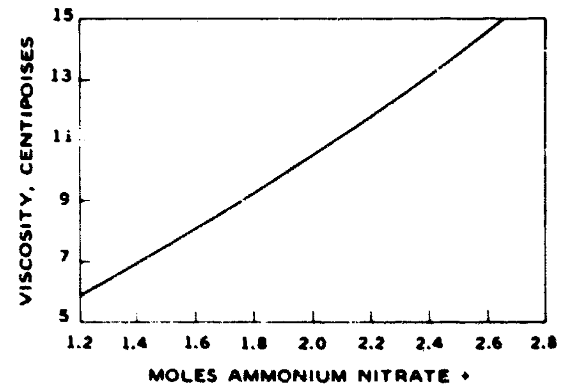


FIG. C-4. Viscosities of Ammonium Nitrate/Urea/Water Solutions at 26°C.

passing air, which had been dried, through a column of Drierite, then through a column of anhydrous magnesium perchlorate, through a saturator tube into an absorption tube containing Drierite, and then through an absorption tube containing anhydrous magnesium perchlorate. The air was then collected over water in 2-liter volumetric flasks. The saturator consisted of a glass tube 110 centimeters long with an inside diameter of 15 millimeters. Glass beads, 4 millimeters in diameter, coated with the solution under test were placed in the saturator tube until it was nearly filled. The temperature of the airstream was continuously monitored with a thermistor at the exit side of the saturator tube. Flow time was measured by an electric timer. Manometric measurement gave a mean value of 5 millimeters of mercury above ambient atmospheric pressure. Baxter and Lansing (Ref. C-2) indicate that gas flow rates of 4 to 1 l/hr are satisfactory. It was found here that flow rates of 2.5 l/hr (42 cm^3/min) were satisfactory for the more dilute solutions, but the flow rate had to be reduced to 1.2 l/hr (20 cm^3/min) or less to obtain reproducible results with the more concentrated solutions. The vapor pressure measurements were made at room temperature. The measured collected air was assumed to be saturated with water and was corrected to dry air. The vapor pressure was calculated as done by Baxter (Ref. C-2) by dividing the volume of the water picked up by the air as it passed through the saturator by the sum of the volume of the water plus the volume of dry air multiplied by the interior pressure (which was taken as 705 millimeters of mercury). The results are estimated to be accurate to ±3%.

Results

The results of the vapor pressure measurements are given in Table C-1 and in Fig. C-5.

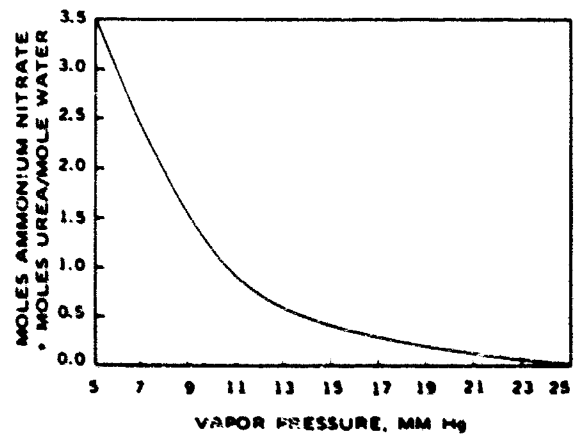


FIG. C-5. Vapor Pressure of Ammonium Nitrate/Urea/Water Solutions at Temperatures Near 26°C.

REFERENCES

C-1. Burkardt, Lohr A., William S. McEwan, and Hayden W. Pitman "Apparatus for Obtaining Heating and Cooling Curves," REV SCI INSTRUM, Vol. 27 (September 1956), pp. 693-95.

C-2. Baxter, G. P., and J. E. Lansing. "The Aqueous Pressure of Some Hydrated Crystals. Oxalic Acid, Strontium Chloride and Sodium Sulfate," AMER CHEM SOC, J., Vol. 42, No. 3 (March 1920), pp. 419-26.

Appendix D

TEST SUMMARY

TABLE D-1. Test Summary.

Test	Date, 1968	Material	Amount	Conditions	Base, ft AGL	Tops, ft AGL	Where seeded	Seeder aircraft	Pattern	Location	Treatment density,[a] g/m^3 X 10^{-}[illegible]
1	29 Mar.	Pyrotechnic	14 2AL2s	Stratus	400	1,400-1,800	Top	...	...	ACV[b]	...
2	29 Mar.	Pyrotechnic	14 2AL2s	Stratus	950	1,800	1,700	...	...	ACV	...
3	31 Mar.	Pyrotechnic	14 EW20s	Frontal	500	1,800-2,400	Top	...	...	ACV	...
4	9 Apr.	Pyrotechnic	14 EW20s	Stratus	400	1,150	950	...	...	ACV	...
5	9 Apr.	Pyrotechnic	12 2AL2s	Stratus	400	1,150	Top	...	...	ACV	...
6	10 Apr.	Pyrotechnic	4 Salty Dogs	Fog	100	1,500	Ground	...	...	ACV	...
7	10 Apr.	Pyrotechnic	28 LW83s	Fog	200	1,400	Top	...	...	ACV	...
8	10 Apr.	Pyrotechnic	28 LW83s	Fog	200	1,500	1,300	...	...	ACV	...
9	8 May	Pyrotechnic	12 WF8s	Stratus	700	1,600	1,400	...	...	ACV	...
10	8 May	Pyrotechnic	10 2AL2s	Stratus	800	1,300	1,000	...	...	ACV	...
11	18 May	Pyrotechnic	10 Salty Frogs	High stratus	...	300	Ground	...	...	ACV	...
12	18 May	Pyrotechnic	28 WF8s, 4 smoke generators	Fog	...	300	1,000	...	...	ACV	...
13	18 May	Pyrotechnic	9 Salty Frogs	Fog	100	300	Ground	...	...	ACV	...
14	3 June	Pyrotechnic	3 Salty Dogs	Fog	100	1,400	Ground	...	...	ACV	...
15	3 June	Pyrotechnic	9 Salty Frogs	Fog	100	1,400	Ground	...	...	ACV	...
16	17 June	Pyrotechnic	37 2AL2s	Fog	200-400	1,100	Base to top	...	Spiral ascent	ACV	...
17	17 June	Pyrotechnic	9 Salty Frogs	Fog	200-400	1,100	Ground	...	...	ACV	...
18	24 June	Pyrotechnic	8 Salty Frogs	Fog	200	1,200	Ground	...	...	ACV	...
19	26 June	Pyrotechnic	8 Salty Frogs	Fog	300	1,300	Ground	...	...	ACV	...
20	10 July	Pyrotechnic	2 Briteyes	Fog	0	1,700	Ground	...	...	ACV	...
21	20 July	Pyrotechnic	12 Salty Frogs	Fog	200	1,500	Ground	...	...	ACV	...
22	23 July	Seawater	400 gal	Stratus	400	1,700	Top	B-25	Orbital	ACV	4.7
23	23 July	Tap water	400 gal	Stratus	300	1,800	Top	B-25	...	At sea	2.1
24	24 July	Tap water	400 gal	Stratus	700	2,400	Top	B-25	...	At sea	1.82
25	27 July	Pyrotechnic	9 Salty Frogs	Fog	0	950	Ground	...	...	ACV	...
26	27 July	Sat. NH_4NO_3 solution	400 g	Fog	0	1,000	Top	B-25	Orbital	ACV	7.9
27	31 July	Sat. NH_4NO_3 solution	800 g	Stratus	300	1,600	Top	B-25	Orbital	ACV	12.3
28	31 July	Tap water	400 gal	Stratus	100	1,400	Top	B-25	Pulsed st. line	At sea	9.6
29	1 Aug.	Pyrotechnic	4 Briteyes	Fog	0	1,500	Ground	B-25	...	ACV	...
30	1 Aug.	NH_4NO_3 solution	800 g	Fog	100	1,500	Top	B-25	Orbital	ACV	14.1
31	1 Aug.	NH_4NO_3 solution	800 g	Stratus	700	2,300	Top	B-25	Orbital spray	At sea	7.7
32	6 Aug.	NH_4NO_3 solution	750 g	Stratus	300	1,500	Top	B-25	Lines of spray	ACV	7.0
33	7 Aug.	Tap water	600 g	Fog	0	750	Top	B-25	Pulsed spray	At sea	33.2

A

TABLE D-1. Test Summary.

Base, ft AGL	Tops, ft AGL	Where seeded	Seeder aircraft	Pattern	Location	Treatment density,[a] $g/m^3 \times 10^{-3}$	Liquid water content, g/m^3		Remarks
							Preseed	Postseed	
400	1,400-1,800	Top	...	...	ACV[b]	...	...	...	Not effective.
950	1,800	1,700	...	...	ACV	...	...	...	Inconclusive.
500	1,800-2,400	Top	...	...	ACV	...	...	...	Not effective.
400	1,150	950	...	...	ACV	...	...	...	Inconclusive.
400	1,150	Top	...	...	ACV	...	...	...	Inconclusive.
100	1,500	Ground	...	...	ACV	...	...	...	White cloud on top 1/4 mi. diam. Large drops downwind. C&V[c] 200 ft and 1/8 mi. to 700 ft and 3 mi. in 10 min. Lasted 1/2 hr.
200	1,400	Top	...	...	ACV	...	...	...	Not effective.
200	1,500	1,300	...	...	ACV	...	...	...	Not effective.
700	1,600	1,400	...	...	ACV	...	...	...	Not effective.
800	1,300	1,000	...	...	ACV	...	...	...	No visual effects. Minilab shows reduction in LWC.
...	300	Ground	...	...	ACV	...	...	...	Clear air burn. Wet cloud formed.
...	300	1,000	...	...	ACV	...	...	...	None.
100	300	Ground	...	...	ACV	...	...	...	2 stations reported holes.
100	1,400	Ground	...	...	ACV	...	...	...	Inconclusive.
100	1,400	Ground	...	...	ACV	...	...	...	Inconclusive.
200-400	1,100	Base to top	...	Spiral ascent	ACV	...	...	...	None.
200-400	1,100	Ground	...	...	ACV	...	...	...	Dome formed; dense white, lasted 40 min. No improvement.
200	1,200	Ground	...	...	ACV	...	...	...	Results inconclusive.
300	1,300	Ground	...	...	ACV	...	...	...	LWC decreased; some mist and bubble on top.
0	1,700	Ground	...	...	ACV	...	...	...	Heavy precip. after burn. Visibility improved, may have been natural
200	1,500	Ground	...	...	ACV	...	...	...	No change, no bubble.
400	1,700	Top	B-25	Orbital	ACV	4.7	...	...	No change.
300	1,800	Top	B-25	...	At sea	2.1	...	...	No change.
700	2,400	Top	B-25	...	At sea	1.82	...	...	No change.
0	950	Ground	...	...	ACV	...	...	...	No visible change. Good bubble on top, LWC inconclusive.
0	1,000	Top	B-25	Orbital	ACV	7.9	...	...	No change in visibility.
300	1,600	Top	B-25	Orbital	ACV	12.3	...	...	Depression in tops, large droplets noted; no change in visibility.
100	1,400	Top	B-25	Pulsed st. line	At sea	9.6	...	...	No results.
0	1,500	Ground	B-25	...	ACV	...	...	...	Some precip.; no change in C&V.
100	1,500	Top	B-25	Orbital	ACV	14.1	...	...	Local enhancement amid natural breakup, reduction of LWC.
700	2,300	Top	B-25	Orbital spray	At sea	7.7	...	...	Inconclusive.
300	1,500	Top	B-25	Lines of spray	ACV	7.0	...	...	0.5 g/m^3 reduction LWC. Distinct growth in droplet size.
0	750	Top	B-25	Pulsed spray	At sea	33.2	...	...	No effects.

B

TABLE D-1. Test Summary. (Contd.)

Test	Date, 1968	Material	Amount	Conditions	Base, ft AGL	Tops, ft AGL	Where seeded	Seeder aircraft	Pattern	Location
34	10 Aug.	NaCl solution	600 g	Fog	0	1,600	1,400	B-25	Pulsed spray	At sea
35	12 Aug.	Urea solution	800 g	Stratus	400	2,400	Top	B-25	Orbital	ACV
36	13 Aug.	Leslie MVF NaCl	800 lb	Stratus	2,500	4,400	Top	C-47	Pulsed powder	At sea
37	15 Aug.	Pyrotechnic	9 CY-91s	Stratus	300	700	Ground	.	.	ACV
38	1 Sept.	$CaCl_2$ powder	400 lb	Stratus	200	1,750	Top	C-47	Racetrack	At sea
39	1 Sept.	$CaCl_2$ powder	400 lb	Stratus	200	1,750	Top	C-47	Racetrack	At sea
40	1 Sept.	$CaCl_2$ powder	400 lb	Stratus	200	1,750	1,650	C-47	Racetrack	At sea
41	4 Sept.	NH_4NO_3 solution	730 g	Fog	300	1,400	Top	B-25	Orbital	ACV
42	4 Sept.	$CaCl_2$ powder	800 lb	Stratus	. . .	1,700	Top	C-47	Pulsed powder	At sea
43	5 Sept.	Morton NaCl	2,000 lb	Stratus	800	2,250	1,300	C-47	Racetrack	At sea
44	5 Sept.	$CaCl_2$ powder	800 lb	Stratus	800	2,250	Top	C-47	Racetrack	At sea
45	6 Sept.	Urea solution	800 g	Fog	200	2,000	1,000	B-25	Orbital	ACV
46	6 Sept.	NaCl powder	2,000 lb	Stratus	900	1,800	Top	C-47	Racetrack	At sea
47	7 Sept.	Urea solution	800 g	Stratus	300	1,900	Top	B-25	Orbital	ACV
48	7 Sept.	NaCl powder	2,600 lb	Stratus	600	1,900	Top	C-47 Cessna 206	Racetrack	At sea
49	8 Sept.	NaCl solution	750 g	Stratus	800	2,000	Top	B-25	Orbital	At sea
50	8 Sept.	$CaCl_2$ powde	1,400 lb	Stratus	800	2,000	Top	C-47 Cessna 206	Parallel track	At sea
51	12 Sept.	NH_4NO_3 solution	800 g	Stratus	600	2,200	Top	B-25	Orbital	ACV
52	12 Sept.	NaCl powder	1,500 lb	Stratus	250	900	Top	C-47	Orbital	At sea
53	13 Sept.	$CaCl_2$ solution	650 g	Stratus	1,000	1,750	Top	B-25	Orbital	At sea
54	27 Sept.	NaCl powder	2,000 lb	Fog	0	700	650	C-47	Racetrack	At sea
55	27 Sept.	$CaCl_2$ powder	1,500 lb	Fog	0	650	700	C-47	Orbital	At sea
56	27 Sept.	$CaCl_2$ powder	1,500 lb	Fog	0	650	700	C-47	Orbital	At sea
57	30 Sept.	NaCl powder	3,000 lb	Stratus	1,500	2,800	Top	C-47	Orbital	At sea
58	30 Sept.	NaCl powder	2,000 lb	Stratus	1,500	2,800	Top	C-47	Racetrack	At sea
59	30 Sept.	9:1 solution	700 g	Stratus	1,800	2,850	Top	B-25	Orbital	At sea
60	1 Oct.	9:1 solution	650 g	Stratus	600	1,700	Top	B-25	Dumbbell	At sea
61	1 Oct.	$CaCl_2$ powder	450 lb	Stratus	450	1,700	Top	C-47	1 pass	At sea

TABLE D-1. Test Summary (Contd.)

Tops, ft AGL	Where seeded	Seeder aircraft	Pattern	Location	Treatment density,[a] g/m^3 X 10^{-3}	Liquid water content, g/m^3		Remarks
						Preseed	Postseed	
1,600	1,400	B-25	Pulsed spray	At sea	24.0	0.6	0.7	Slight increase in LWC. No visual effects.
2,400	Top	B-25	Orbital	ACV	6.2	. . .	. . .	Weakening of cloud structure; wide distrails.
4,400	Top	C-47	Pulsed powder	At sea	4.7	0.7	0.4	Depression of LWC.
700	Ground	. . .	. . .	ACV	. . .	. . .	. . .	Slight increase in precip. No increase in C&V.
1,750	Top	C-47	Racetrack	At sea	4.12	0.3	0.3	No apparent results.
1,750	Top	C-47	Racetrack	At sea	5.13	Up to 3		LWC rise below track; no visual results.
1,750	1,650	C-47	Racetrack	At sea	2.41	0.8	0.2	LWC reduction; no visual results.
1,400	Top	B-25	Orbital	ACV	13.9	. . .	. . .	Droplets grew; on-top depression.
1,700	Top	C-47	Pulsed powder	At sea	17.6	. . .	. . .	Bright spot, no hole.
2,250	1,300	C-47	Racetrack	At sea	20.2	. . .	. . .	No apparent results.
2,250	Top	C-47	Racetrack	At sea	11.3	Decrease of 0.2 to 0.3		LWC reduction for 5 to 6 min.
2,000	1,000	B-25	Orbital	ACV	5.7	0.1	0.3	Short-lived increase in LWC; no apparent results.
1,800	Top	C-47	Racetrack	At sea	13.0	. . .	. . .	Short-lived increase in LWC; bright spot below.
1,900	Top	B-25	Orbital	ACV	5.75	. . .	. . .	No change. Trough for 10 min.. Slight improvement underneath.
1,900	Top	C-47 Cessna 206	Racetrack	At sea	13.9	. . .	. . .	No change in LWC. Trough and bright spots.
2,000	Top	B-25	Orbital	At sea	18.6	. . .	. . .	Short-lived trough.
2,000	Top	C-47 Cessna 206	Parallel track	At sea	12.2	. . .	. . .	No effects in LWC; short-lived trough.
2,200	Top	B-25	Orbital	ACV	12.6	. . .	. . .	No effects in LWC. Localized improvement amid slower clearing.
900	Top	C-47	Orbital	At sea	13.5	. . .	. . .	Minor troughing.
1,750	Top	B-25	Orbital	At sea	6.7	. . .	. . .	Only minor changes in LWC. Speedup of natural dissipation. Holes.
700	650	C-47	Racetrack	At sea	12.6	0.2	. . .	100-yd-wide furrow, 1/2 mi., lasted 10 min.
650	700	C-47	Orbital	At sea	5.7	No Minilab data		No apparent effects.
650	700	C-47	Orbital	At sea	7.4	spikes, 2 to 3		Brightening in seeded trail.
2,800	Top	C-47	Orbital	At sea	7.0	0.7	1.8	Above normal LWC; no effects from on top.
2,800	Top	C-47	Racetrack	At sea	32.0	. . .	. . .	No change, LWC. No effects from on top.
2,850	Top	B-25	Orbital	At sea	7.1	0.2	0.7	No effects on top; high LWC in cloud in seeded area.
1,700	Top	B-25	Dumbbell	At sea	50.0	0.5	1.5	No visible effects; some distrail widening.
1,700	Top	C-47	1 pas	At sea	46.8	0.5	1.6	Augers jammed. Some trail deepening.

B

TABLE D-1. Test Summary. (Contd.)

Test	Date, 1968	Material	Amount	Conditions	Base, ft AGL	Tops, ft AGL	Where seeded	Seeder aircraft	Pattern	Location	Treatm[illegible] densit[illegible] g/m³ X [illegible]
62	9 Oct.	9:1 solution	700 g	Fog	0	800	Top	B-25	Dumbbell	At sea	83.
63	24 Oct.	9:1 solution	10 g	Fog	0	900	Ground	(Fog Sweep)	. . .	ACV	. . .
64	24 Oct.	9:1 solution	750 g	Fog	0	900	Top	B-25	Orbital	ACV	37.
65	25 Oct.	9:1 solution	750 g	Fog	0	700-1,100	Top	B-25	Dumbbell	[illegible]V	68.
66	25 Oct.	Urea powder	1,500 lb	Fog	0	600	Top	C-47	Racetrack	ACV	12.
67	30 Oct.	9:1 solution	400 g	Cumulus	2,000	8,200	7,700	B-25	Dumbbell	East of ACV	4.
68	5 Nov.	9:1 solution	750 g	Cumulus	1,000	8,000	Top	B-25	Dummbell	North of ACV	54.
69	6 Nov.	4:1 solution	2,700 g	Fog	0	720	Top	B-25 2 C123s	Dumbbell	Medford airport	307.
70	7 Nov.	9:1 solution	2,700 g	Fog	0	800	Top	B-25 2 C123s	Racetrack	Hoopa Valley	295.
71	9 Nov.	9:1 solution	2,700 g	Fog	200	1,200	Top	B-25 2 C123s	Racetrack	ACV	230.
72	10 Nov.	9:1 solution	1,950 g	Fog	200	2,300	Top	2 C123s	Racetrack	West of Garberville	350.

[a] Swath width assumed to be 100 meters in treatment density calculations.
[b] Arcata-Eureka airport.
[c] Ceiling and visibility.

A

TABLE D-1. Test Summary. (Contd.)

..., ...GL	Tops, ft AGL	Where seeded	Seeder aircraft	Pattern	Location	Treatment density,[a] g/m³ X 10⁻³	Liquid water content, g/m³		Remarks
							Preseed	Postseed	
0	800	Top	B-25	Dumbbell	At sea	83.4	0.5	1.9	Thinning; bright spots. Improved vertical visibility.
0	900	Ground	(Fog Sweep)	. . .	ACV	. . .	. . .	. . .	Fog sweep broke down.
0	900	Top	B-25	Orbital	ACV	37.6	. . .	. . .	Hole, 1/2-mi. diam. Ceiling rise 200 ft, low LWC, rise in RVR.
0	700-1,100	Top	B-25	Dumbbell	ACV	68.6	0.3	0.1	Large hole over ACV. RVR improvement, millimeter drops.
0	600	Top	C-47	Racetrack	ACV	12.5	0.2	2.0	Some clearing at ACV.
00	8,200	7,700	B-25	Dumbbell	East of ACV	4.4	. . .	. . .	Tops lowered, bases up. Darkening and precip.
00	8,000	Top	B-25	Dummbell	North of ACV	54.4	1.0	1.0	Cell diminished.
0	720	Top	B-25 2 C123s	Dumbbell	Medford airport	307.8	0.2	0.2	Holes formed; RVR showed no improvement.
0	800	Top	B-25 2 C123s	Racetrack	Hoopa Valley	295.4	. . .	. . .	Wide seed tracks, breakup downwind.
00	1,200	Top	B-25 2 C123s	Racetrack	ACV	230.4	0.1	0.4	Hole and dramatic clearing at ACV; above min. for 1 1/2 hr.
00	[illegible],300	Top	2 C123s	Racetrack	West of Garberville	350.0	. . .	. . .	Hole in seed track; breakup in general area.

B

TABLE D-2. Ceiling and Visibility (C&V).

Test	Date, 1968	Preseed conditions		Conditions during seeding, ceiling (ft) & visibility (mi) at 10-min intervals												Thickness, ft.	
		Ceiling, ft	Visibility, mi	0 + 10		0 + 20		0 + 30		0 + 40		0 + 50		0 + 60			
				C	V	C	V	C	V	C	V	C	V	C	V		
6	10 Apr.	100	1/4	100	1/2	100	1/2	100	1/2	100	1/2	100	1/2	100	1/2	1,400	
14	3 June	100	1	...	3/4	...	1/2	...	1/2	...	1/2	...	3/4	...	...	...	C&V decreas
16	17 June	200-400	1	...	...	...	...	...	...	...	...	...	...	...	...	800	Plume caused
17	17 June	200-400	2	...	...	...	...	...	...	...	...	...	...	...	...	800	Plume caused
18	24 June	200	1/2	200	1	200	7	...	...	...	...	...	...	200	7	1,000	Visibility inc
19	26 June	300	3/4	...	...	...	...	300	1	300	1	...	...	...	...	1,000	
20	10 July	0	0	...	...	...	...	200	1/2	...	...	...	...	...	...	1,700	
21	20 July	200	3/16	200	1/4	200	1/4	200	1/2	200	1/2	...	...	200	3/4	1,300	
22	23 July	400	1 1/2	...	...	400	1 1/2	...	...	...	...	...	...	200	3/4	1,300	
25	27 July	0	1/8	0	3/16	0	1/8	0	3/8	0	1/8	0	1/16	0	1/8	900	
26	27 July	0	1/16	...	...	...	...	...	...	100	1/4	...	...	...	...	1,000	
27	31 July	300	1 1/2	...	...	...	...	400	1 1/2	...	...	...	...	400	1 1/2	1,300	
29	1 Aug.	100	1/4	0	1/16	100	1/16	200	1/16	250	1/8	250	1/8	250	1/8	1,500	
30	1 Aug.	100	1/4	...	...	...	...	...	...	200	3/4	...	...	300	1 1/2	1,700	Minilab pilot
32	6 Aug.	300-600	2	...	...	...	...	...	...	...	...	...	...	500	2	900	C&V high at
35	12 Aug.	400	5	...	...	...	...	...	...	400	7	...	...	...	...	2,000	
37	15 Aug.	0	...	...	...	...	...	...	...	...	...	...	...	...	...	400	No improvem
41	4 Sept.	300	1	...	...	...	...	...	...	...	...	...	...	300	1	1,100	Minilab pilot
45	6 Sept.	200	3/4	400	2	...	...	...	...	...	...	...	...	600	3	1,800	
46	6 Sept.	900	...	...	...	...	...	...	...	...	...	...	...	...	...	1,800	Bright spot o
47	7 Sept.	300	2	400	2	400	2	400	2	300	2	300	2	300	2	1,600	
48	7 Sept.	600	5	800	...	...	...	...	...	...	...	...	...	...	...	1,300	Boat crew s
51	12 Sept.	1,200	1	...	...	...	...	200	1/2	...	...	...	...	200	1/2	...	Poor conditi
63	24 Oct.	0	1/8	...	...	...	...	...	...	...	...	0	1/16	...	...	900	Fog sweep b
64	24 Oct.	0	1/16	...	...	200	1/2	...	...	...	...	...	...	0	1/16	900	Hole formed
65	24 Oct.	0	1/8	Hole	3/4	Hole	3/4	Hole	3/4	0	1/4	0	1/4	100	1/2	900	Hole formed
66	25 Oct.	0	1/4	100	1/4	100	1/2	...	...	100	1/2	...	...	...	...	600	Short-lived h
67	30 Oct.	2,000	...	...	...	...	...	...	...	...	...	...	...	...	...	6,200	Cumulus tes
68	5 Nov.	1,000	...	...	...	...	...	...	...	...	...	...	...	...	...	7,000	Cumulus tes
69	6 Nov.	100	1/8	100	3/8	100	3/8	100	1/2	100	1/2	...	...	300	1/2	700	4:1 solution
70	7 Nov.	...	...	...	...	...	...	...	...	...	...	...	...	...	...	800	Hole develo
71	9 Nov.	200	1/8	...	1/4	300	1/2	300	1	Hole	1 1/2	Hole	1	200	3/4	1,000	Hole develo
72	10 Nov.	200	...	...	...	...	...	...	...	...	...	...	...	.	...	2,100	No C&V we

A

TABLE D-2. Ceiling and Visibility (C&V).

Conditions during seeding, ceiling (ft) & visibility (mi) at 10-min intervals											Thickness, ft.	Remarks
0 + 10	0 + 20		0 + 30		0 + 40		0 + 50		0 + 60			
V	C	V	C	V	C	V	C	V	C	V		
1/2	100	1/2	100	1/2	100	1/2	100	1/2	100	1/2	1,400	...
3/4	...	1/2	...	1/2	...	1/2	...	3/4	...	...	...	C&V decreased.
...	...	...	...	...	...	...	...	...	...	...	800	Plume caused decrease.
...	...	...	...	...	...	...	...	...	...	...	800	Plume caused decrease.
1	200	7	...	...	...	...	...	...	200	7	1,000	Visibility increased.
...	...	...	300	1	300	1	...	...	...	...	1,000	...
...	...	...	200	1/2	...	...	...	...	...	...	1,700	...
1/4	200	1/4	200	1/2	200	1/2	...	...	200	3/4	1,300	...
...	400	1 1/2	...	...	...	...	...	...	200	3/4	1,300	...
3/16	0	1/8	0	3/8	0	1/8	0	1/16	0	1/8	900	...
...	...	...	...	...	100	1/4	...	...	...	...	1,000	...
...	...	...	400	1 1/2	...	...	...	...	400	1 1/2	1,300	...
1/16	100	[illegible]	200	1/16	250	1/8	250	1/8	250	1/8	1,500	...
...	...	...	...	...	200	3/4	...	...	300	1 1/2	1,700	Minilab pilot reported breakout.
...	...	...	...	...	...	...	...	...	500	2	900	C&V high at beginning, went up during test.
...	...	...	...	...	400	7	...	...	...	...	2,000	...
...	...	...	...	...	...	...	...	...	...	...	400	No improvement in C&V.
...	...	...	...	...	...	...	...	...	300	1	1,100	Minilab pilot reported slight increase in ceiling.
2	...	...	...	...	...	...	...	...	600	3	1,800	...
...	...	...	...	...	...	...	...	...	...	...	1,800	Bright spot observed by boat crew, lasted 10 min.
2	400	2	400	2	300	2	300	2	300	2	1,600	...
...	...	...	...	...	...	...	...	...	...	...	1,300	Boat crew saw ceiling raise 200 to 400 ft, lasted 10 min.
...	...	...	200	1/2	...	...	...	...	200	1/2	...	Poor conditions, variable clouds.
...	...	...	...	...	...	...	0	1/16	...	...	900	Fog sweep broke down; test canceled.
...	200	1/2	...	...	...	...	...	...	0	1/16	900	Hole formed, 1/2-mi. diameter. Ceiling and RVR went up.
3/4	Hole	3/4	Hole	3/4	0	1/4	0	1/4	100	1/2	900	Hole formed, near VFR conditions.
1/4	100	1/2	...	...	100	1/2	...	...	...	...	600	Short-lived hole at ACV.
...	...	...	...	...	...	...	...	...	...	...	6,200	Cumulus test, cloud collapsed.
...	...	...	...	...	...	...	...	...	...	...	7,000	Cumulus test.
3/8	100	3/8	100	1/2	100	1/2	...	...	300	1/2	700	4:1 solution at Medford. Small holes formed.
...	...	...	...	...	...	...	...	...	...	...	800	Hole developed at Hoopa Valley.
1/4	300	1/2	300	1	Hole	1 1/2	Hole	1	200	3/4	1,000	Hole developed, RVR went to 6,000+.
...	...	...	...	...	...	...	...	...	...	...	2,100	No C&V west of Garberville. Hole formed.

B

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) Naval Weapons Center China Lake, CA 93555	2a. REPORT SECURITY CLASSIFICATION UNCLASSIFIED 2b. GROUP

3. REPORT TITLE

PROJECT FOGGY CLOUD I

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

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

E. Alex Blomerth, R. S. Clark, H. E. Cronin, J. R. Ennis, R. L. Lininger, D. W. Reed, P. St.-Amand, W. C. White, T. L. Wright.

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
August 1970	85	9

8a. CONTRACT OR GRANT NO. b. PROJECT NO. c. AIRTASK A370-5401/216C/0W 3712-0000 d.	9a. ORIGINATOR'S REPORT NUMBER(S) NWC TP 4929 9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)

10. DISTRIBUTION STATEMENT

THIS DOCUMENT IS SUBJECT TO SPECIAL EXPORT CONTROLS AND EACH TRANSMITTAL TO FOREIGN GOVERNMENTS OR FOREIGN NATIONALS MAY BE MADE ONLY WITH PRIOR APPROVAL OF THE NAVAL WEAPONS CENTER.

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY Naval Air Systems Command Naval Material Command Washington, DC 20360

13. ABSTRACT

Foggy Cloud I was a series of experiments in observation, modification, and treatment of fog and stratus clouds conducted at or near the Arcata-Eureka airport, Humboldt County, Calif., from late March through mid-November 1968.

Civil and military personnel from the Navy, Army, and Air Force participated in the experiments, aided by contractor personnel and local representatives of the Federal Aviation Administration, National Bureau of Standards, Humboldt County Director of Aviation, and the Coast Guard.

A wide range of prospective seeding agents, including smokes, liquids, and powders, that were thought to offer promise for stabilization or clearance of fog were systematically screened by ground-based and airborne dissemination. The major emphasis was placed upon the elimination of fog rather than upon simply improving visibility.

Those agents showing enough identifiable effects to indicate promise were investigated in detail and improved upon. Observations were made of fog characteristics, visual effects, changes in cloud physics parameters, and of the fallout from the fog.

Hygroscopic smokes were found useful for intensifying, stabilizing, and forming fog and stratus. Hygroscopic powders, including sodium chloride, urea, and calcium chloride, were tried. Of these, calcium chloride showed the most promise, but testing was not completed.

Hygroscopic liquids showed the most immediate results, and successful tests were made with ammonium nitrate in solution. In October, a solution consisting of ammonium nitrate, urea, and water was developed that was used in several very successful field trials.

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Weather Modification Fog Dispersal Warm Fog Seeding Techniques						

DD FORM 1 NOV 65 1473 (BACK)
(PAGE 2)

ABSTRACT CARD

Naval Weapons Center

Project Foggy Cloud I, by E. Alex Blomerth, White Sands Missile Range, R. S. Clark, H. E. Cronin, J. R. Ennis, R. L. Lininger, MAJ, USAF, D. W. Reed, CAPT, USA, P. St.-Amand, W. C. White, and T. L. Wright. China Lake, Calif., NWC, August 1970. 85 pp. (NWC TP 4929, publication UNCLASSIFIED.)

Foggy Cloud I was a series of experiments in observation, modification, and treatment of fog and stratus clouds conducted at or near the Arcata-Eureka airport, Humboldt County, Calif., from late March through mid-November 1968.

Civil and military personnel from the Navy, Army, and Air Force participated in the experiments, aided by contractor personnel and local representatives of the

(Over)
2 cards, 8 copies

Naval Weapons Center

Project Foggy Cloud I, by E. Alex Blomerth, White Sands Missile Range, R. S. Clark, H. E. Cronin, J. R. Ennis, R. L. Lininger, MAJ, USAF, D. W. Reed, CAPT, USA, P. St.-Amand, W. C. White, and T. L. Wright. China Lake, Calif., NWC, August 1970. 85 pp. (NWC TP 4929, publication UNCLASSIFIED.)

Foggy Cloud I was a series of experiments in observation, modification, and treatment of fog and stratus clouds conducted at or near the Arcata-Eureka airport, Humboldt County, Calif., from late March through mid-November 1968.

Civil and military personnel from the Navy, Army, and Air Force participated in the experiments, aided by contractor personnel and local representatives of the

(Over)
2 cards, 8 copies

Naval Weapons Center

Project Foggy Cloud I, by E. Alex Blomerth, White Sands Missile Range, R. S. Clark, H. E. Cronin, J. R. Ennis, R. L. Lininger, MAJ, USAF, D. W. Reed, CAPT, USA, P. St.-Amand, W. C. White, and T. L. Wright. China Lake, Calif., NWC, August 1970. 85 pp. (NWC TP 4929, publication UNCLASSIFIED.)

Foggy Cloud I was a series of experiments in observation, modification, and treatment of fog and stratus clouds conducted at or near the Arcata-Eureka airport, Humboldt County, Calif., from late March through mid-November 1968.

Civil and military personnel from the Navy, Army, and Air Force participated in the experiments, aided by contractor personnel and local representatives of the

(Over)
2 cards, 8 copies

Naval Weapons Center

Project Foggy Cloud I, by E. Alex Blomerth, White Sands Missile Range, R. S. Clark, H. E. Cronin, J. R. Ennis, R. L. Lininger, MAJ, USAF, D. W. Reed, CAPT, USA, P. St.-Amand, W. C. White, and T. L. Wright. China Lake, Calif., NWC, August 1970. 85 pp. (NWC TP 4929, publication UNCLASSIFIED.)

Foggy Cloud I was a series of experiments in observation, modification, and treatment of fog and stratus clouds conducted at or near the Arcata-Eureka airport, Humboldt County, Calif., from late March through mid-November 1968.

Civil and military personnel from the Navy, Army, and Air Force participated in the experiments, aided by contractor personnel and local representatives of the

(Over)
2 cards, 8 copies

NWC TP 4929

Federal Aviation Administration, National Bureau of Standards, Humboldt County Director of Aviation, and the Coast Guard.

A wide range of prospective seeding agents, including smokes, liquids, and powders, that were thought to offer promise for stabilization or clearance of fog were systematically screened by ground-based and airborne dissemination. The major emphasis was placed upon the elimination of fog rather than upon simply improving visibility.

Those agents showing enough identifiable effects to indicate promise were investigated in detail and improved upon. Observations were made of fog characteristics, visual effects, changes in cloud physics parameters, and of the fallout from the fog.

Hygroscopic smokes were found useful for intensifying, stabilizing, and forming fog and stratus. Hygroscopic powders, including sodium chloride, urea, and calcium chloride, were tried. Of these, calcium chloride showed the most promise, but

(Contd. on Card 2)

NWC TP 4929

Federal Aviation Administration, National Bureau of Standards, Humboldt County Director of Aviation, and the Coast Guard.

A wide range of prospective seeding agents, including smokes, liquids, and powders, that were thought to offer promise for stabilization or clearance of fog were systematically screened by ground-based and airborne dissemination. The major emphasis was placed upon the elimination of fog rather than upon simply improving visibility.

Those agents showing enough identifiable effects to indicate promise were investigated in detail and improved upon. Observations were made of fog characteristics, visual effects, changes in cloud physics parameters, and of the fallout from the fog.

Hygroscopic smokes were found useful for intensifying, stabilizing, and forming fog and stratus. Hygroscopic powders, including sodium chloride, urea, and calcium chloride, were tried. Of these, calcium chloride showed the most promise, but

(Contd. on Card 2)

NWC TP 4929

Federal Aviation Administration, National Bureau of Standards, Humboldt County Director of Aviation, and the Coast Guard.

A wide range of prospective seeding agents, including smokes, liquids, and powders, that were thought to offer promise for stabilization or clearance of fog were systematically screened by ground-based and airborne dissemination. The major emphasis was placed upon the elimination of fog rather than upon simply improving visibility.

Those agents showing enough identifiable effects to indicate promise were investigated in detail and improved upon. Observations were made of fog characteristics, visual effects, changes in cloud physics parameters, and of the fallout from the fog.

Hygroscopic smokes were found useful for intensifying, stabilizing, and forming fog and stratus. Hygroscopic powders, including sodium chloride, urea, and calcium chloride, were tried. Of these, calcium chloride showed the most promise, but

(Contd. on Card 2)

NWC TP 4929

Federal Aviation Administration, National Bureau of Standards, Humboldt County Director of Aviation, and the Coast Guard.

A wide range of prospective seeding agents, including smokes, liquids, and powders, that were thought to offer promise for stabilization or clearance of fog were systematically screened by ground-based and airborne dissemination. The major emphasis was placed upon the elimination of fog rather than upon simply improving visibility.

Those agents showing enough identifiable effects to indicate promise were investigated in detail and improved upon. Observations were made of fog characteristics, visual effects, changes in cloud physics parameters, and of the fallout from the fog.

Hygroscopic smokes were found useful for intensifying, stabilizing, and forming fog and stratus. Hygroscopic powders, including sodium chloride, urea, and calcium chloride, were tried. Of these, calcium chloride showed the most promise, but

(Contd. on Card 2)

ABSTRACT CARD

Naval Weapons Center
Project Foggy Cloud . . . (Card 2)
testing was not completed.

Hygroscopic liquids showed the most immediate results, and successful tests were made with ammonium nitrate in solution. In October, a solution consisting of ammonium nitrate, urea, and water was developed that was used in several very successful field trials.

NWC TP 4929

Naval Weapons Center
Project Foggy Cloud . . . (Card 2)
testing was not completed.

Hygroscopic liquids showed the most immediate results, and successful tests were made with ammonium nitrate in solution. In October, a solution consisting of ammonium nitrate, urea, and water was developed that was used in several very successful field trials.

NWC TP 4929

Naval Weapons Center
Project Foggy Cloud . . . (Card 2)
testing was not completed.

Hygroscopic liquids showed the most immediate results, and successful tests were made with ammonium nitrate in solution. In October, a solution consisting of ammonium nitrate, urea, and water was developed that was used in several very successful field trials.

NWC TP 4929

Naval Weapons Center
Project Foggy Cloud . . . (Card 2)
testing was not completed.

Hygroscopic liquids showed the most immediate results, and successful tests were made with ammonium nitrate in solution. In October, a solution consisting of ammonium nitrate, urea, and water was developed that was used in several very successful field trials.

NWC TP 4929