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Project Foggy Cloud III, Phase I

by

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ABSTRACT

Foggy Cloud III, Phase I is part of a continuing series of experiments concerning the modification and dispersal of warm fog and stratus clouds. Tests were conducted at the Arcata-Eureka Airport, Humboldt County, Calif. from 27 July to 24 October 1970, using fixed-wing aircraft as delivery vehicles. The seeding agents were (1) a solution of ammonium nitrate, urea, and water developed during Foggy Cloud I, and (2) water.

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FOREWORD

Project Foggy Cloud is a continuing research and development program conducted for AIR-540, Naval Air Systems Command, by the Earth and Planetary Sciences Division of the Research Department, Naval Weapons Center.

Foggy Cloud III, the third in a series of warm fog modification experiments, began 27 July and ended 24 October 1970. A primary project objective was to raise ceilings and visibilities at a fog-shrouded airport using a project-developed hygroscopic solution.

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

Released by
PIERRE ST.-AMAND, *Head*
Earth and Planetary Sciences Division
8 October 1971

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

CONTENTS

Summary ... 1

Introduction ... 2
- Background ... 2
- Selection of Site ... 3
- Previous Foggy Cloud Efforts ... 4
- Arcata Fogs ... 4

Project Foggy Cloud III ... 10
- Objectives ... 10
- Phases ... 11
- Organization ... 11
- Planning ... 11

Project Equipment ... 12
- General ... 12
- Project Aircraft ... 12
- Project Ground Equipment ... 18

Experimental Techniques ... 21
- Project Alert System ... 21
- Standard Operations Schedule ... 21
- Flight Patterns ... 22
- Seeding Agent ... 24
- Treatment Density ... 26
- Surface Observations ... 27

Experimental Data ... 27
- Data Collection and Reduction ... 27
- Analysis and Reporting ... 28

Test Results ... 30
- Support Tests ... 30
- Selected Tests ... 30
- Summary of Individual Tests ... 55
- Test Evaluation Under Steady-State Fog Conditions ... 62

Conclusions and Recommendations ... 63
- Conclusions ... 63
- Recommendations ... 63

Appendixes:

A. Catalog of Data Collected 64
B. Support Test Summary 65

References 66

Figures:

1. Arcata-Eureka Airport 2
2. Project Site and Instrumentation Location 3
3. Topographic Chart, Arcata-Eureka Airport 5
4. Low-Visibility Conditions at the Arcata-Eureka Airport, by Month, for 1957 through 1966 6
5. Typical Weather Pattern for Development of Coastal Advection Fog at Arcata, 1600 PST, 17 August 1970 7
6. Typical Weather Pattern for Radiation Fog Formation at Arcata, 0400 PST, 17 September 1970 8
7. Comparative Transmissivity Study at the Arcata-Eureka Airport; Low Visibility (Transmissivity <50%) 9
8. Comparative Ceiling and Visibility Study at the Arcata-Eureka Airport, 0500 to 1200 PST, 1968 through 1970 10
9. Project Organization 11
10. B-26, Primary Seeder Aircraft 13
11. DC-7, Secondary Seeder Aircraft 13
12. DC-7 Interior Showing Solution Tanks and Associated Equipment 14
13. Cessna 337, Minilab Aircraft 14
14. Minilab Console Installation 16
15. Cessna 206, Aerial Photography Aircraft 17
16. T-11 Aerial Camera 17
17. Cessna 401, Control/Observation Aircraft 18
18. Radar Units 19
19. Preparations for Sounding 20
20. Solution Holding and Loading Facility 20
21. Standard Operations Schedule 22
22. Kneeland Airport, Altitude 2,750 Feet MSL 23
23. Radar Plot of Seeding Pattern, Test III-16A, 2 October 1970 24
24. Minilab Data Passes 25
25. Photography Aircraft Track at Standard Altitude of 10,000 Feet 25
26. Minilab Data From Test III-9A 29
27. Visibility Reference Photograph 30
28. Test III-4A, Arcata Rawinsonde, 0648 LST, 16 August 1970 31
29. Test III-4A, Ceiling and Visibility 32
30. Test III-4A, Average Pass Values From South End to North End of Runway 31 32
31. Test III-4A, Surface Conditions Before and After Seeding 33
32. Test III-5A, Arcata Rawinsonde, 0832 LST, 18 August 1970 34

Figures (Contd.)

33. Test III-5A, Ceiling and Visibility 35
34. Test III-5A, Average Pass Values From South End to North End of Runway 31 36
35. Test III-5A, Surface Conditions Before and After Seeding 37
36. Test III-12A, Arcata Rawinsonde, 0642 LST, 29 August 1970 38
37. Test III-12A, Ceiling and Visibility 39
38. Test III-12A, Runway Visual Range From Transmissometer 40
39. Test III-12A, Relative Drop Count and Median Size 41
40. Test III-12A, Surface Conditions Before and After Seeding 42
41. Test III-15A, Arcata Rawinsonde, 0738 LST, 28 September 1970 43
42. Test III-15A, Ceiling and Visibility 44
43. Test III-15A, Average Pass Values From South End to North End of Runway 31 45
44. Test III-15A, Surface and Fog Top Conditions During and After Seeding 46
45. Test III-16A, Arcata Rawinsonde, 0939 LST, 2 October 1970 51
46. Test III-16A, Ceiling and Visibility 52
47. Test III-16A, Relative Drop Count and Median Size 53
48. Test III-16A, Average Pass Values From South to North End of Runway 31 54
49. Test III-16A, Surface Conditions Before and After Seeding 54

Tables:

1. Project Aircraft and Major Equipment 12
2. Minilab Variables and Specifications 15
3. Data on Ammonium Nitrate-Urea-Water System 26
4. Corrosion of Various Test Materials by an Equimolar Ammonium Nitrate-Urea-Water Solution 26
5. Principal Data and Source 28
6. Summary of Test Seeding Operations 56
7. Effects of Seeding Stable Fog With 9:1 Solution 62
8. Catalog of Data Collected 64
9. Support Test Summary 65

SUMMARY

From 27 July to 24 October 1970, the Naval Weapons Center, working in collaboration with the Navy Weather Research Facility, and with support from the U.S. Army, the Federal Aviation Administration, the National Bureau of Standards, and the Humboldt County Department of Aviation, conducted Phase I of Project Foggy Cloud III. The project was based at the Arcata-Eureka Airport in northern California, where several such projects have been conducted in the past.

Although the project had several objectives, its primary purpose was to develop an operational warm fog dispersal system.

Phase II of Foggy Cloud III was a joint effort with the U.S. Army Atmospheric Sciences Laboratory, White Sands Missile Range. This phase consisted of a series of rotary-blade downwash studies using a CH-54A Skycrane helicopter. Phase II will be reported separately.

Nineteen tests were conducted during Phase I. The seeding agent in 17 tests was a project-developed hygroscopic solution of ammonium nitrate, urea, and water. This solution consisted, by weight, of 4 parts ammonium nitrate, 3 parts urea, and 0.78 part water, giving a solids-to-water ratio of 9:1. The other two tests were conducted with tap water.

Seeder aircraft employed were a B-26 with a 1,000-gallon solution payload and a DC-7 with a 3,000-gallon payload. The DC-7 was under contract for only a short period, and because of equipment problems and a low incidence of fog, the planned series of DC-7 tests was incomplete.

Emphasis was directed toward raising ceilings and improving visibilities on the surface rather than attempting to eliminate total fog layers. It was found that this was entirely possible on fogs in a steady growth state; however, tests on fogs that were in a dynamic growth state produced less visible results.

INTRODUCTION

BACKGROUND

The Foggy Cloud fog dissipation studies were begun in 1968 in response to a requirement for military aircraft operations under conditions of reduced visibility (Ref. 1). Foggy Cloud III was the third in a series of field experiments applying the knowledge, new equipment, and hygroscopic agents developed during previous field experiments and gathered from laboratory investigations and computer studies.

The objective of these efforts is to develop an economical reliable warm fog dispersal system. These projects have been conducted at the Arcata-Eureka Airport (Fig. 1), McKinleyville, Calif., for the past three seasons.

FIG. 1. Arcata-Eureka Airport.

SELECTION OF SITE

The principal reasons for selecting the Arcata-Eureka Airport as the test site were

1. A high incidence of fog.

2. A relatively low airport traffic volume.

3. Excellent facilities, including navigational aids, office and work space, storage buildings, and auxiliary airfields.

4. A knowledge of the characteristics of the fog, available from many previous studies, for example, by the National Bureau of Standards (Ref. 2) and the Aeronautical Icing Research Laboratories (Ref. 3, 4, and 5).

5. Excellent support provided by local authorities, including the Federal Aviation Administration (FAA), National Bureau of Standards (NBS), and the Humboldt County Department of Aviation.

6. A unique array of transmissometer installations in addition to standard meteorological instrumentation. The location of these instruments is shown in Fig. 2.

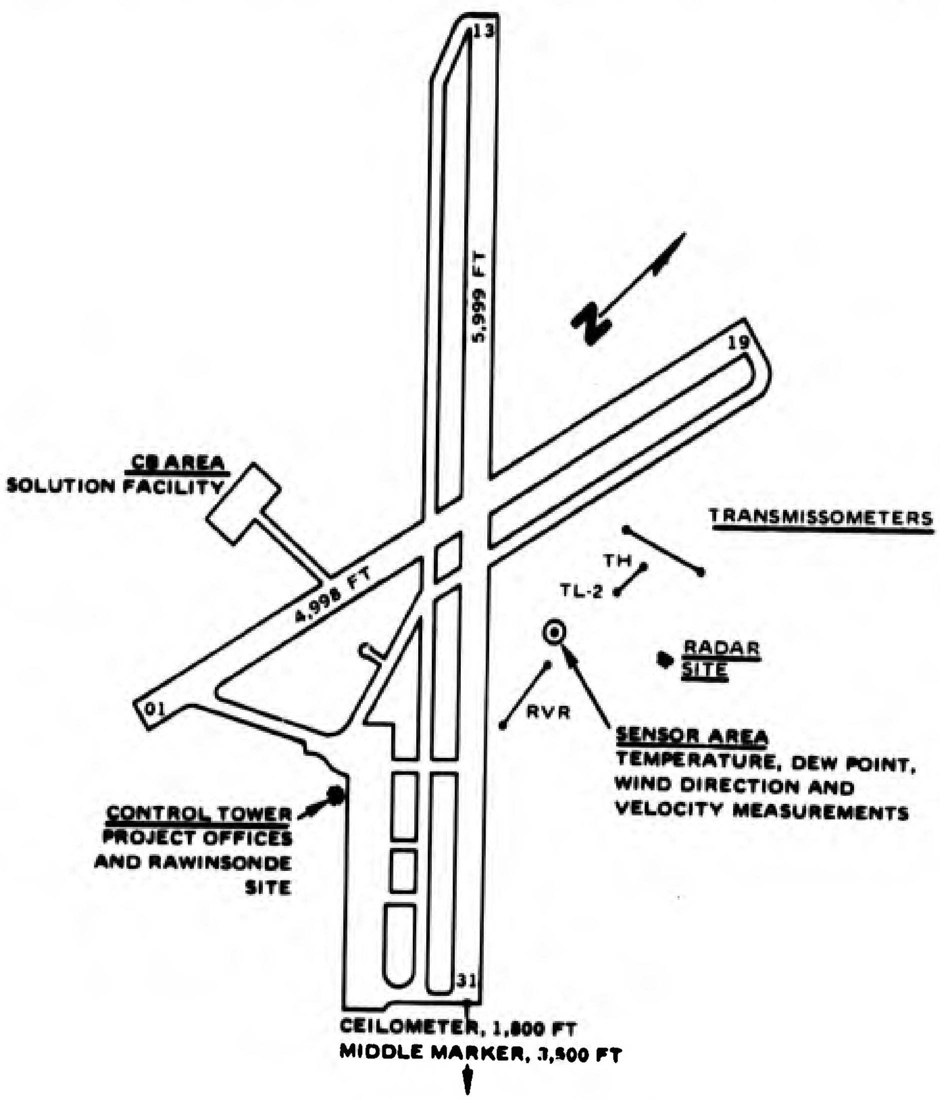

FIG. 2. Project Site and Instrumentation Location.

PREVIOUS FOGGY CLOUD EFFORTS

The initial project of the series, Foggy Cloud I (Ref. 1), was a screening program. Both ground-based and airborne agent-dissemination systems were examined. Candidate agents for both stabilization and dispersal of fog were tested; these included hygroscopic smokes, liquids, and powders.

Seeding with pyrotechnically generated hygroscopic agents was accomplished by light aircraft or by in-place burning on the ground. Hygroscopic powders and liquids were dispensed by aircraft. Those agents showing the most promise were retested. Late in the project, a mixture containing approximately equimolar ratios of ammonium nitrate, urea, and water was selected as the most promising hygroscopic agent.

With the development of the ammonium nitrate-urea-water solution, the contract seeder aircraft was supplemented by two Air Force C-123 Ranch Hand aircraft. These tests were successful and in some cases spectacular. It was concluded that with this equipment and the hygroscopic agent we had developed, an emergency type fog dispersal system was available.

The second project of the series, Foggy Cloud II, had as principal objectives:

1. Continuation of multiple-aircraft seeding
2. Development of improved delivery systems
3. Optimization of such treatment variables as delivery rate, droplet size, and flight pattern

Two seeder aircraft were used during this project. The aircraft had a combined load capacity of 1,700 gallons of hygroscopic agent. Effects attributable to seeding were noted in 94% of the test cases. The final report on this project is in process.

As in 1968, one of the more noteworthy developments occurred toward the end of the project. This development was in-fog seeding at approximately 500 feet above the fog base. This technique cleared a tunnel in the fog over the runway and brought the field above operating minimums. In an unpublished memorandum, September 1969, NWC stated that this enhanced clearing was due to centrifugal separation of fog droplets by the wing-tip vortices.

During this project considerable effort was directed toward optimizing spray rates and droplet sizes. Theory and fog modeling computations (Ref. 6) indicated that small droplets about 50 microns in diameter should be the most efficient in effecting fog clearings within a reasonable time frame.

In experimental work, large holes through thick fog layers were not attained in all cases; however, it was found that in a large percentage of cases, the ceilings and visibilities were markedly improved within a time frame coinciding reasonably with the seeding operation.

Further work with wind tunnel experiments suggests that the droplets produced at the aircraft speeds used, 130 knots IAS, are smaller than 50 microns. This tentative conclusion needs further experimental verification.

ARCATA FOGS

Arcata is located on the California coast about 80 miles south of the Oregon border. Local topographic features (Fig. 3) that play an important role in fog formation and development processes are (1) the coastline orientation, which is north-northeast adjacent to the airport and breaks sharply to the northwest just

FIG. 3. Topographic Chart, Arcata Eureka Airp

phic Chart, Arcata-Eureka Airport.

north of the airport, creating an eddy effect under certain conditions; (2) a 200-foot bluff between the beach and airport (note the contour packing in Fig. 3), which provides an orographic mechanism for intensifying fogs as they move inland; and (3) the surrounding hilly terrain from the north through southeast, which entraps and limits the inland extent of fogs.

As shown in Fig. 4, taken from NBS Report 9958 (Ref. 2), fog occurs during all months of the year, with the greatest incidence during the summer and fall months.

Summer fogs are characterized as coastal advection fogs. Maritime Pacific air flows eastward across the colder coastal wate ., with subsequent fog formation as the surface layer of air is cooled. This advection of marine air is enhanced by inland thermal low-pressure areas that develop as a result of intense heating over the mountains and valleys. A typical afternoon condition that leads to the development of coastal fog the following morning is shown in Fig. 5 (note the 37°F temperature difference between Arcata and Red Bluff). The weather pattern is cyclic, with alternate 3- to 5-day periods of fog and partly cloudy skies. Fog thickness varies considerably, with bases from 0 to 300 feet above ground level (AGL) and tops averaging 1,000 feet; however, tops exceeding 1,500 feet are not unusual.

Radiation fogs, which were uncommon early in the test period, begin to appear in late September. Although these fogs are more shallow, averaging about 500 feet in thickness, they are more intense at the surface, with ceilings always at or near zero. This type of fog normally forms on the first or second day after a "wet," early-season, cold frontal passage. Skies must become sufficiently clear to permit daytime heating and nighttime cooling of the earth's surface. Turbulent

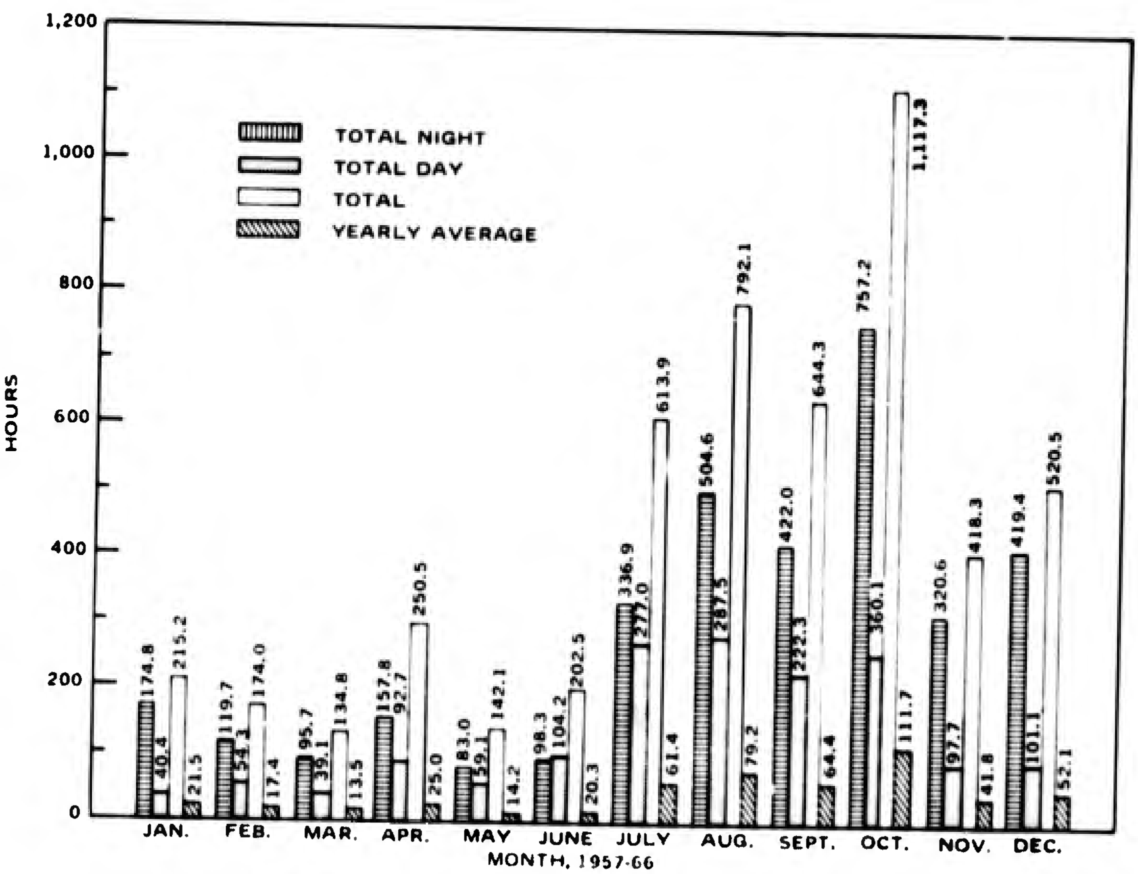

FIG. 4. Low-Visibility Conditions at the Arcata-Eureka Airport, by Month, for 1957 through 1966.

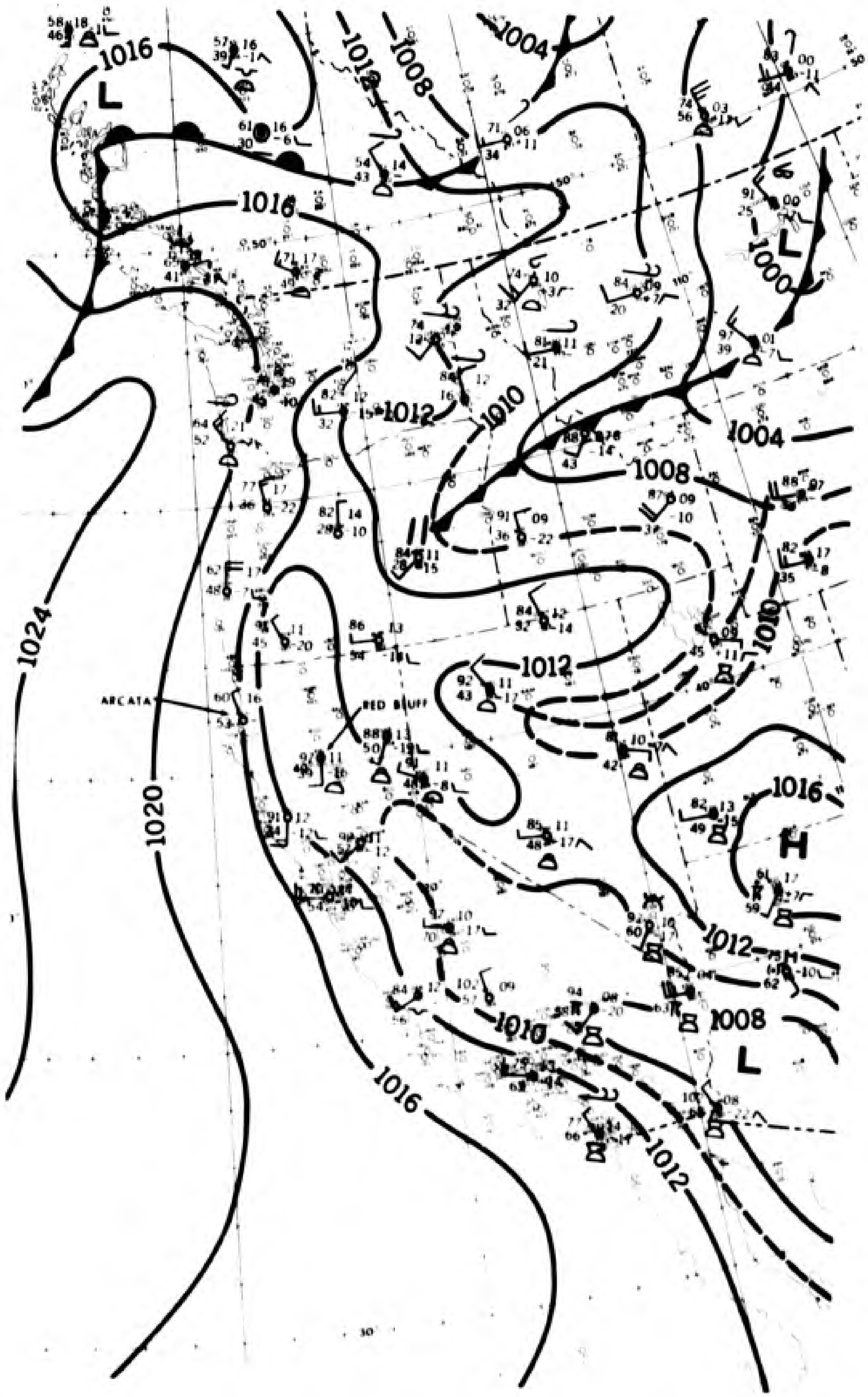

FIG. 5. Typical Weather Pattern for Development of Coastal Advection Fog at Arcata, 1600 PST, 17 August 1970.

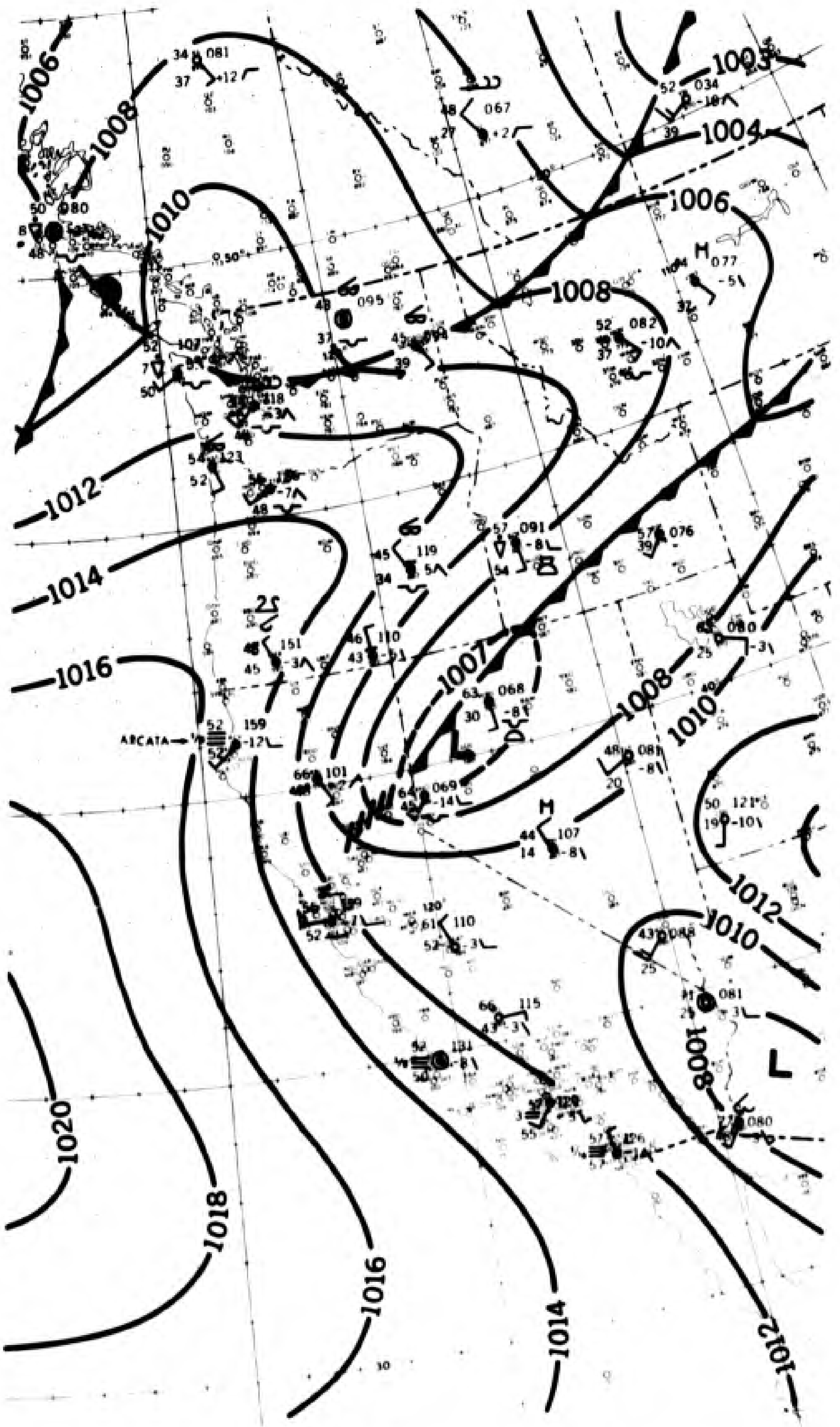

FIG. 6. Typical Weather Pattern for Radiation Fog Formation at Arcata, 0400 PST, 17 September 1970.

effects associated with the front must have ceased, with winds becoming light and variable. Figure 6 depicts typical conditions under which radiation fog develops at Arcata. The weak cold front extending through southeastern Idaho and northwestern Nevada passed over the Arcata area the previous day, in the form of scattered rain showers. These fogs are localized and normally burn off during late morning or early afternoon hours.

During the course of Foggy Cloud III, it became apparent that the incidence of preferred dense fog conditions was below normal. Subsequently, two separate comparative studies were accomplished. The first (Fig. 7) compares the NBS 10-year (1957-1966) transmissivity study with a lik study for the 3-year (1963-1970) tenure of Foggy Cloud. The most significant point in this study is the drastic decrease (both night and day) in the incidence of fog during the month of October. The second study (Fig. 8) compares periods of low ceilings and reduced visibilities for the 3 years of the project. As was expected, during the months of August, September, and October 1970, the incidence of dense fog was considerably less than in 1968 and 1969. The month of July 1970, prior to project operations, had the greatest incidence of dense fog.

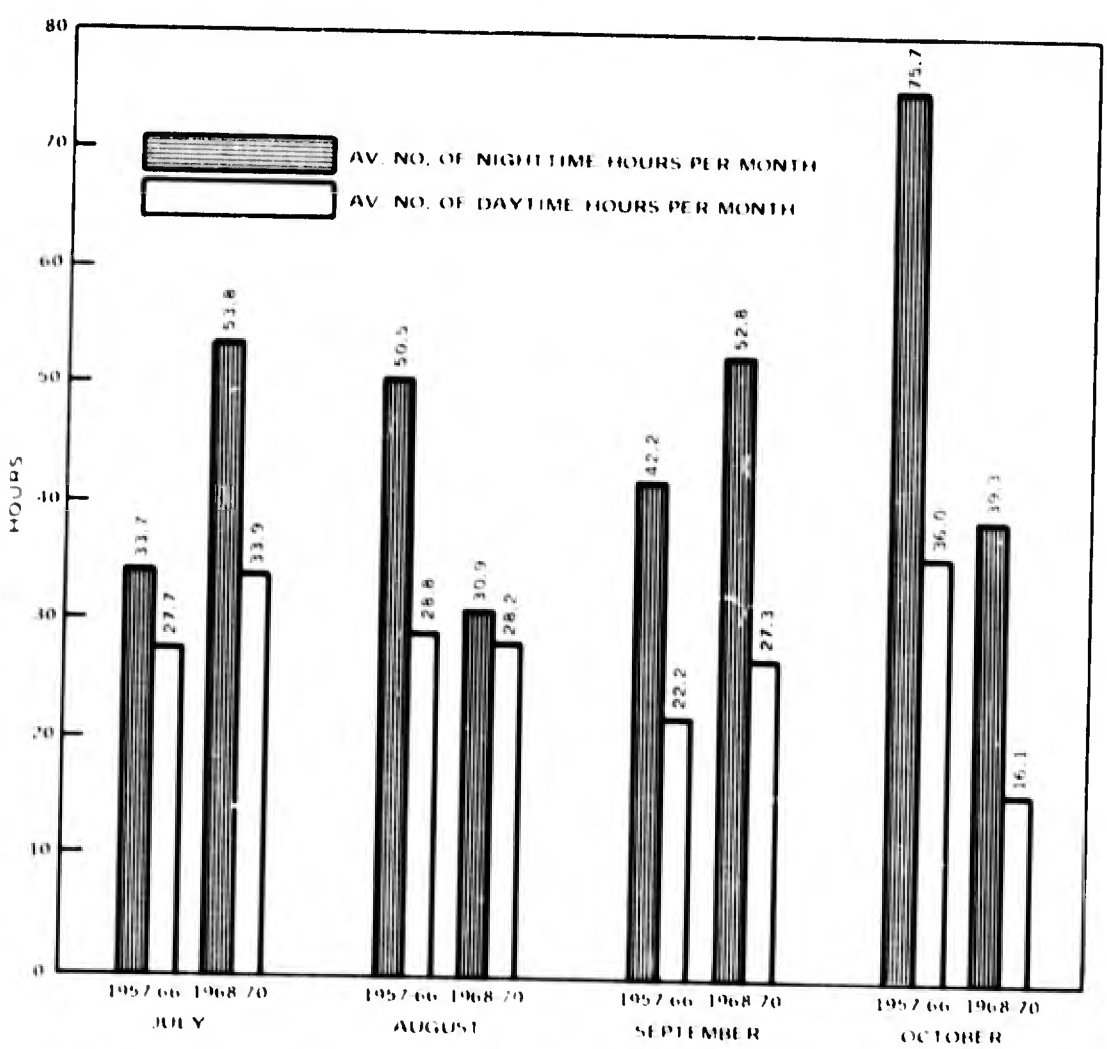

FIG. 7. Comparative Transmissivity Study at the Arcata-Eureka Airport, Low Visibility (Transmissivity < 50%)

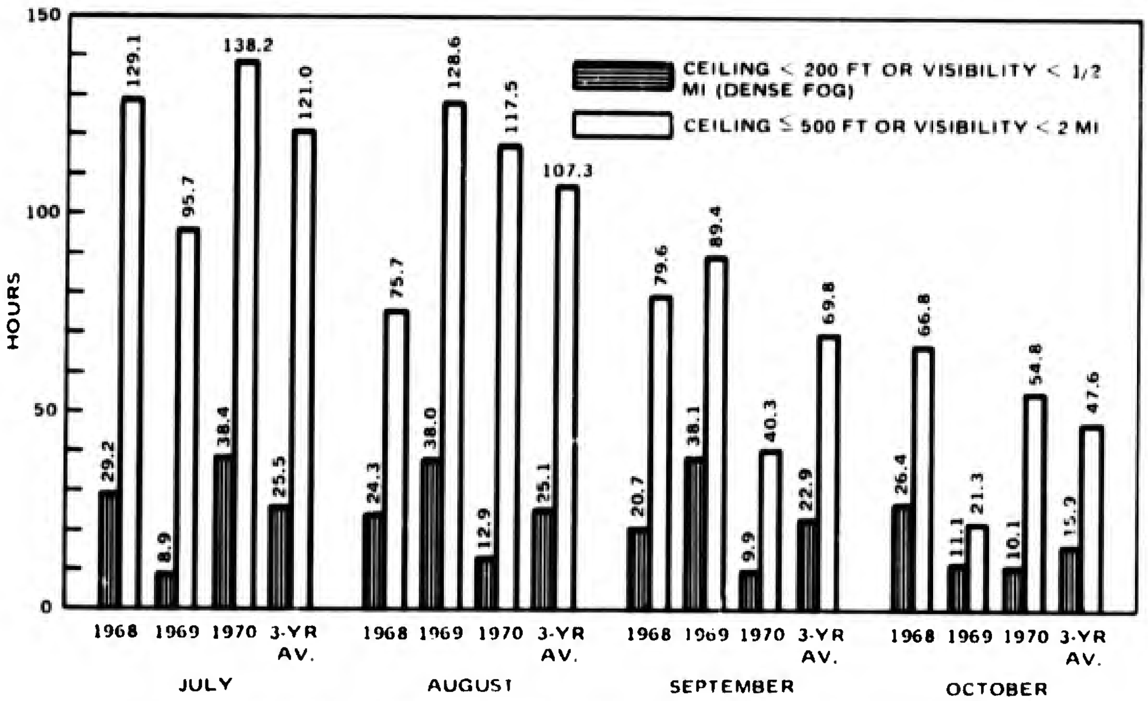

FIG. 8. Comparative Ceiling and Visibility Study at the Arcata-Eureka Airport, 0500 to 1200 PST, 1968 through 1970.

PROJECT FOGGY CLOUD III

OBJECTIVES

This project was conducted during the period 27 July to 24 October 1970 and had the following principal objectives:[1]

1. Determination of the effects of liquid chemicals and dry powders on warm fog and stratus clouds
2. Refinement of dispensing techniques for operational dissipation of warm fog
3. Study of the effects of rotary-blade downwash in combination with chemicals and water
4. Establishment of the feasibility of enhancing coalescence efficiency by spraying charged droplets

Secondary objectives included

1. Collection of background information needed for warm fog modeling
2. Advanced development of spray delivery systems
3. Collection of information needed for rotary-wing downwash pattern studies

[1] Naval Weapons Center. Foggy Cloud III, Experimental Plan 2-70, by Earth and Planetary Sciences Division, China Lake, Calif., NWC, July 1970. 34 pp

PHASES

The project was divided into two overlapping phases that were distinguished by type of delivery vehicle. Phase I, the subject of this report, used fixed-wing aircraft as delivery vehicles; Phase II, which will be described in a joint Atmospheric Sciences Laboratory/Naval Weapons Center report, used a CH-54A Skycrane helicopter as the delivery vehicle.

As in the 2 previous years, Arcata was selected as the test site, not only for the reasons previously stated, but because it is desirable to continue testing in an area in which the climatic conditions have become familiar to the researchers.

ORGANIZATION

Project organization is shown in Fig. 9. Aircraft services were provided by McDonnell Enterprises, Lancaster, Calif., and Weather Science, Inc., Norman, Okla. The Army Meteorological Support Team was provided by the U.S. Army Meteorological Support Activity, Fort Huachuca, Ariz. All other project personnel were provided by the Naval Weapons Center.

PLANNING

Planning for this project was greatly facilitated by a conference held on 2 March 1970 at China

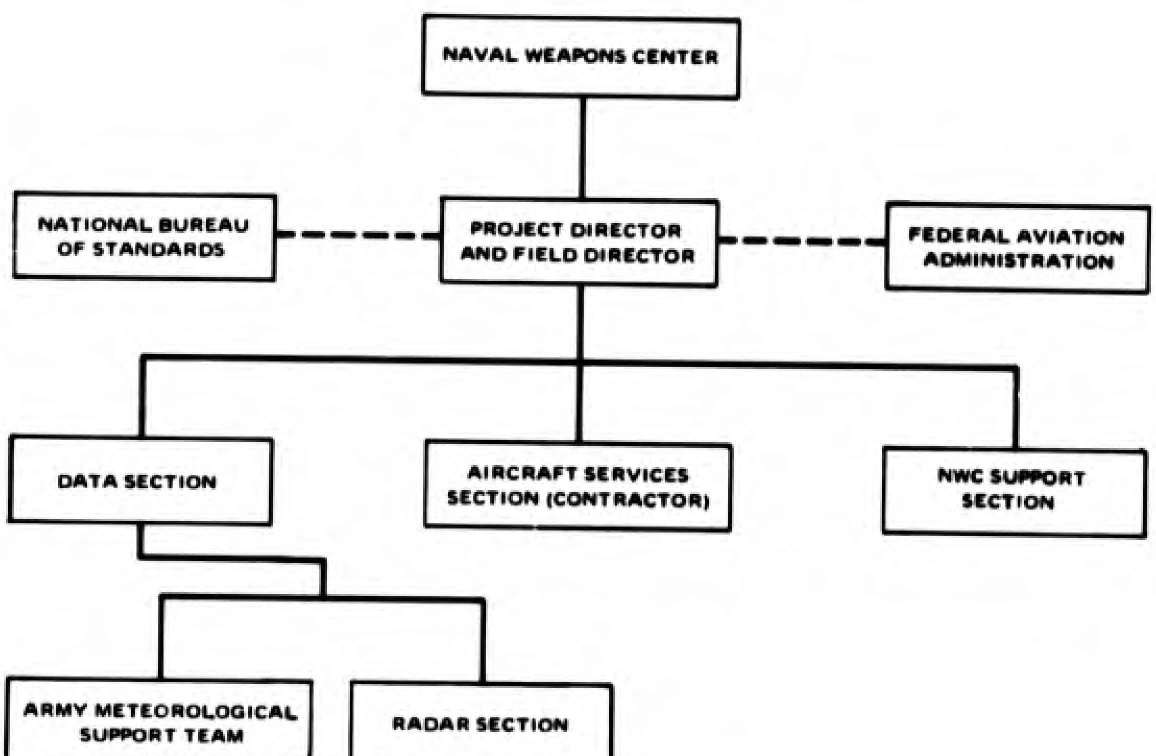

FIG. 9. Project Organization.

Lake. Representatives from the Navy Weather Research Facility, Norfolk, Va.; the U.S. Army Atmospheric Sciences Laboratory, White Sands, N. Mex.; Desert Research Institute, Reno, Nev.; Weather Science, Inc., Norman, Okla.; and the Naval Weapons Center attended the conference. Preliminary plans for the project were presented by the Naval Weapons Center. The Navy Weather Research Facility and Weather Science, Inc. presented their views of warm fog modeling.

After this conference, comments and recommendations for additions, changes, and deletions to the plans were submitted by the conferees. These comments were evaluated and, if appropriate, incorporated into the Experimental Plan.[1]

PROJECT EQUIPMENT

GENERAL

Aircraft and major equipment used for project tests are shown in Table 1. Small devices and data-gathering aids, such as hand-held cameras, standard meteorological instruments, microscopes, calculators, droplet slides, and urea-sensitive paper, are not shown.

PROJECT AIRCRAFT

The B-26, primary seeder aircraft, had a 1,425-gallon solution tank in the bomb bay. Due to weight limitations the aircraft was restricted to 1,000 gallons of hygroscopic solution or 1,200 gallons of water. The tank was insulated and heated. Mounted directly behind the tank were two Simplex pumps driven by a Corvair engine. The spray booms measured 50 feet from tip to tip, had 92 nozzle positions, and were also heated. This system had a maximum dispensing rate of about 250 gal/min. The B-26 in Fig. 10 is shown spraying.

The DC-7, secondary seeder aircraft (Fig. 11), was under contract to the

TABLE 1. Project Aircraft and Major Equipment.

Unit	Function	Special features
B-26	Primary seeder aircraft	1,425-gal tank capacity, spray booms
DC-7	Secondary seeder aircraft	4,950-gal tank capacity, spray booms
Cessna 401	Control/observation aircraft	Backup Minilab, 16-mm movies
Cessna 337	Minilab aircraft	Minilab (Airborne Meteorological System 19)
Cessna 206	Photography aircraft	T-11 aerial camera
Radar	Tracking and plotting	Modified T-33 and TPS-1D
Solution facility	Storage and loading	20,000-gal capacity
Rawinsonde (GMD)	Vertical profile soundings	High-resolution capability
Airport instruments	Weather observations	Standard, with ceilometer and transmissometers
Weather facsimile	Weather charts	Standard (national network)

FIG. 10. B-26, Primary Seeder Aircraft.

FIG. 11. DC-7, Secondary Seeder Aircraft.

project for a limited time (30 days). Unfortunately, due to equipment trouble and a scarcity of suitable fog conditions, the planned series of tests using this aircraft was incomplete. It was equipped with six 825-gallon tanks that were interconnected and controlled by electric shutoff valves. Figure 12 shows the DC-7 interior. The pump system consisted of a 600-gal/min Harmon pump driven by a Corvair engine. This system was enclosed in a stainless-steel box mounted on the cabin floor just aft of the tanks. The spray booms, hung on the trailing edge of each wing, were 80 feet wide from tip to tip and had 150 nozzle positions. Although the tanks had a total

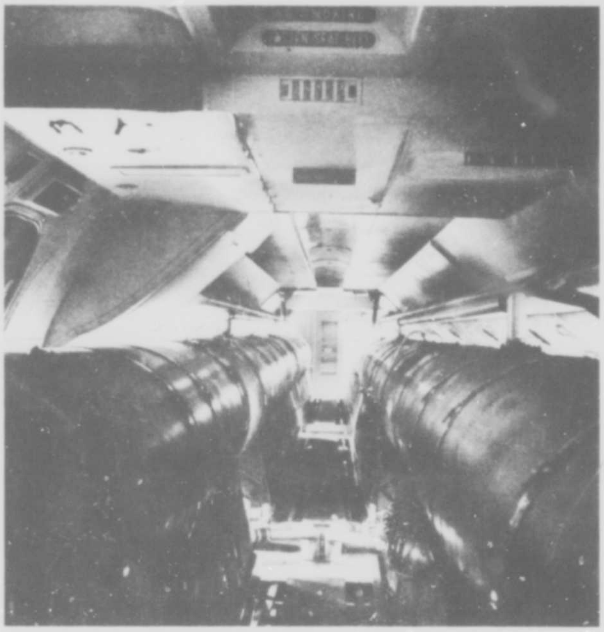

FIG. 12. DC-7 Interior Showing Solution Tanks and Associated Equipment.

FIG. 13. Cessna 337, Minilab Aircraft.

combined capacity of 4,950 gallons, weight limitations restricted payloads to 3,000 gallons of hygroscopic solution or 3,500 gallons of water. Dispensing rates varied up to a maximum of about 425 gal/min.

Figure 13 shows the Cessna 337 Minilab aircraft in flight. The Minilab (Airborne Meteorological System 19) is a product of Weather Science, Inc. Externally mounted sensors measured temperature, dew point, liquid water content (LWC), and airspeed, while internal sensors measured time and altitude. Manufacturer's specifications are presented in Table 2. Although this system is configured to measure additional parameters, they are not discussed here since they are not pertinent to the study of fogs. Detailed descriptions of the Minilab system are available in the appropriate systems manuals. The Minilab console installation is shown in Fig. 14.

The Minilab system was equipped with an 18-channel oscillographic recorder and a magnetic-tape digital recorder. Oscillographic records were principally used as a backup in the event of failure of the digital recorder. The latter uses cartridges with 1/4-inch-wide magnetic tape and records either continuously (2.4 observations per second) or at an interval of 10 seconds, 1 minute, 10 minutes, or 1 hour. The oscillograph records analog voltages continuously at selectable speeds of 1/4, 1, 4, 16, or 64 in/min. Digital recorder tape recordings were mailed to Weather Science, Inc. for computerized data reduction; data turnaround took 5 to 6 days.

A Cessna 206 aircraft (Fig. 15) was used for aerial photography. This plane was equipped with an aerial downward-pointing T-11 camera (Fig. 16) and had the sole task of providing photographic documentation of the fog top. The aircraft

TABLE 2. Minilab Variables and Specifications.

Variable	Instrument	Range	Accuracy	Maximum time constant	Digital recorder resolution
Time	Crystal-controlled clock	0 to 24 hr (1 day)	±2 sec/day	Not applicable	1 sec
Altitude	CIC[a] pressure transducer	0 to 33,200 ft	±166 ft	1.0 sec	33 ft
Indicated airspeed	CIC[a] pressure transducer	70 to 368 knots	±1.46 knots	1.0 sec	0.37 knot
Temperature	Thermistor and amplifier	+50 to −50°C	0 to +50°C ±0.2°C, −1 to −30°C ±0.3°C, −30 to −50°C ±0.5°C	1.0 sec	0.05°C
Dew point	Cambridge Systems	+50 to −50°C	0 to +50°C ±1.0°C, 0 to −50°C ±0.5°C	0.5°C/sec	0.1°C
Liquid water content	Johnson-Williams	0 to 6 g/m^3	0.05 g/m^3	1.0 sec	0.006 g/m^3
Event condition[b]	MSI[c] EC22	0 to 999 units	1 unit	Not applicable	1 unit

[a] Consolidated Instrument Corp.
[b] Permits coded inputs onto a tape by the operator.
[c] Meteorological Services, Inc.

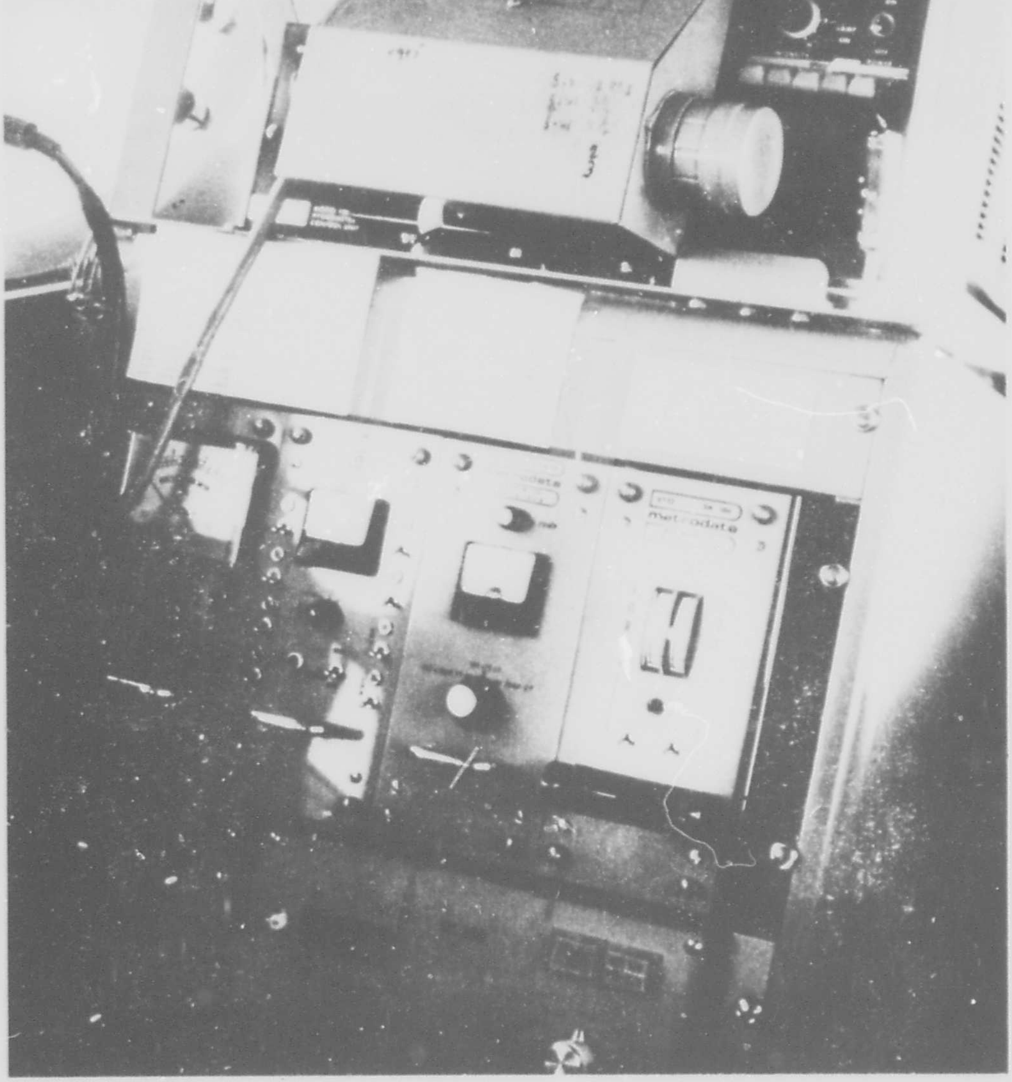

FIG. 14. Minilab Console Installation.

FIG. 15. Cessna 206, Aerial Photography Aircraft.

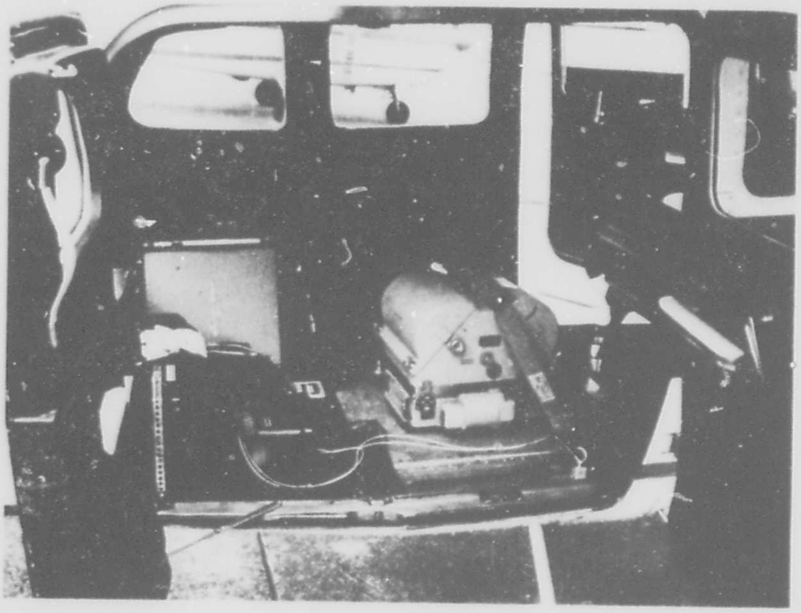

FIG. 16. T-11 Aerial Camera.

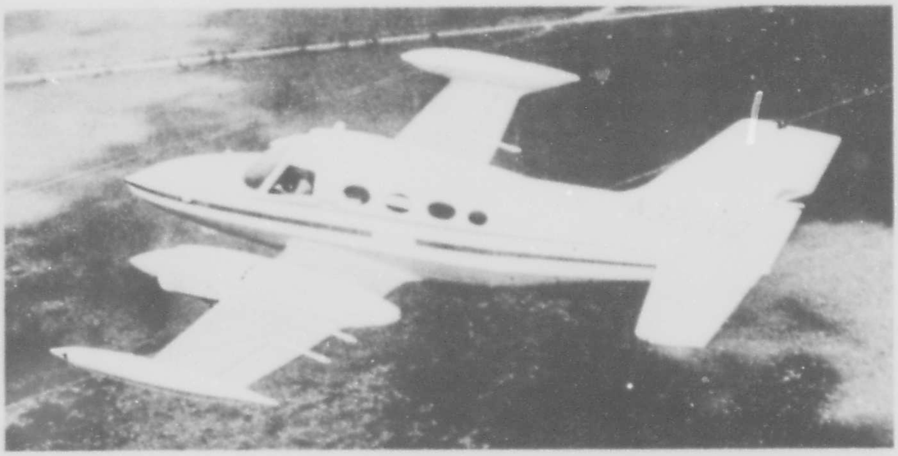

FIG. 17. Cessna 401, Control/Observation Aircraft.

normally flew a prescribed course down the localizer (radio beam) at an altitude of 10,000 feet above the fog top. This positioning permitted a view of 9 mi^2 per photograph (3 miles on a side). Since the camera was activated at a known position (over the middle marker) and operated through an intervalometer, any given photograph could be located along the localizer reasonably well. This is discussed further under Experimental Techniques. Examples of photographs obtained from this source are shown in the discussion of Test III-15A under Test Results.

A Cessna 401 aircraft (Fig. 17) was used as a control/observation aircraft. The project director could monitor and direct the operations from a vantage point above the operations. This aircraft was also equipped with a Minilab and served as a backup in that capacity. Motion picture films (16-mm) were taken routinely from this aircraft. This vantage point was extremely valuable during Foggy Cloud I and II; however, with the advent of in-cloud seeding during Foggy Cloud III, Phase I, it lost its importance. With emphasis directed toward raising ceilings and improving visibilities, surface observations were of prime importance.

PROJECT GROUND EQUIPMENT

The radar unit (Fig. 18), which controlled all seeding operations and monitored all aircraft in the area, consisted of modified T-33 and TPS-1D radars.

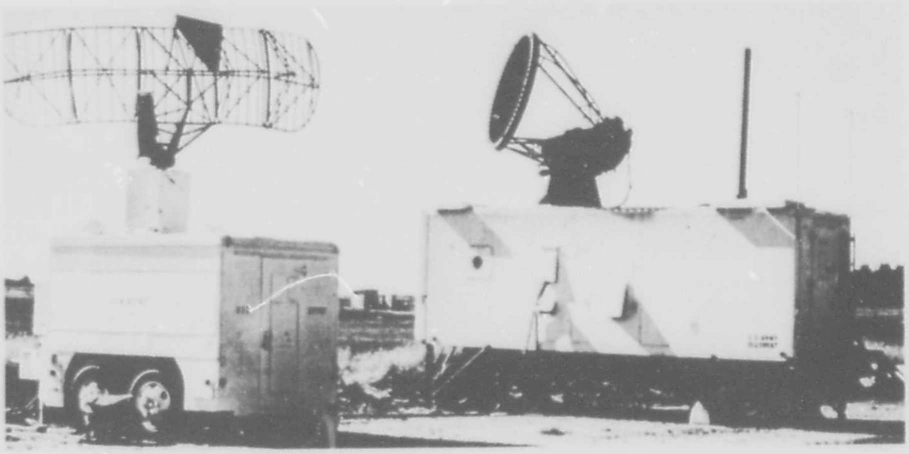

FIG. 18. Radar Units.

The T-33, equipped with a computer and plotting board, provided plots of all seeding operations.

The Army Meteorological Support Team assigned to the project conducted atmospheric soundings and provided vertical profiles of the fog and adjacent atmosphere as required. Three soundings per test were normally made to define fog properties, vertical extent, and mass motion. A vector wind, from the surface to the seeding altitude, was computed and used for targeting. The unit was equipped with a modified GMD rawinsonde system and had the capability of providing high-resolution soundings. This technique, detailed in U.S. Weather Bureau Technical Memorandum WBTM WR-41 (Ref. 7), provides for a continuous readout of temperature and relative humidity with altitude. Preparations for a sounding are pictured in Fig. 19.

A solution holding and loading facility (Fig. 20) was fabricated and installed at Arcata before tests were begun. This facility consisted of two 10,000-gallon solution tanks and a 2,000-gallon water tank. The solution tanks were made of carbon-steel plate that was coated and insulated to prevent corrosion and heat loss. A liquid line filter for 15-micron nominal retention was installed, and each tank was equipped with an internal immersion heater in order to maintain the solution at the desired temperature. The solution tanks had interconnecting plumbing, permitting circulation or exchange. The water tank was used for flushing the pumps and plumbing systems and for washing down aircraft. This facility could load an aircraft with filtered solution at the rate of 125 gal/min.

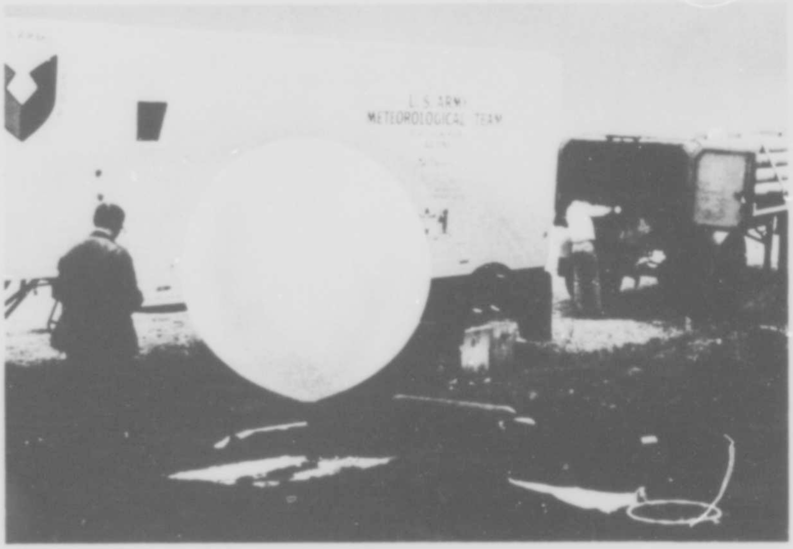

FIG. 19. Preparations for Sounding.

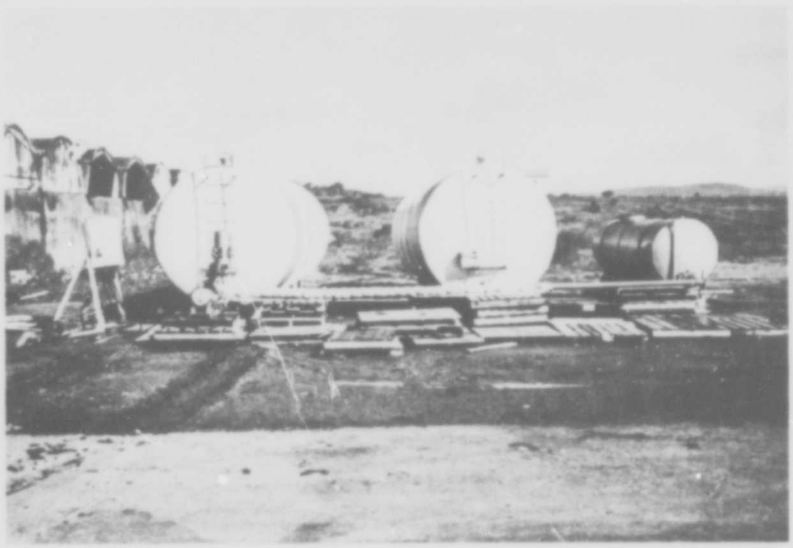

FIG. 20. Solution Holding and Loading Facility.

EXPERIMENTAL TECHNIQUES

PROJECT ALERT SYSTEM

Experience during Foggy Cloud I and II proved that test scheduling based on fog forecasting was not entirely satisfactory and resulted in several missed test opportunities. With the multitude of tasks to be performed, the project could not afford the luxury of a meteorologist devoting full time to practical weather forecasting. Therefore, during Foggy Cloud III an alert system was developed in coordination with the FAA to minimize the requirement for accurate forecasting. However, fog forecasting still remained important for scheduling project off days. Depending on weather conditions, a given day might be spent in testing or in supporting activities such as maintenance and data reduction, or it might be declared an off day.

STANDARD OPERATIONS SCHEDULE

During preoperational planning it was recognized that solar radiation produces important, unavoidable changes in fog. On the other hand, daylight is a requirement for photographic and visual documentation of changes. To reduce day-to-day differences in solar effects, seeding operations were planned at the same time each day with respect to sunrise. In reality, however, this approach was seldom realized. Late-developing fogs, equipment malfunction, and airport traffic caused unforeseen delays.

The success of the experiments depended on precise operational procedures. In general, these procedures (Fig. 21) were as follows:

1. A preoperations briefing was held about 2 hours before sunrise.

2. Ground-based observers, data collectors, and support personnel were deployed and commenced assigned tasks.

3. The Minilab and photography aircraft were launched and commenced preseed fog sampling and photographic documentation.

4. The seeder aircraft was launched, acquired by radar, and kept under control.

5. A balloon-borne weather radiosonde was released to provide a vertical profile of fog properties, and a vector wind was computed. This wind vector was used to determine fog movement and thereby determine when the treated fog volume was over the airport.

6. Shortly after sunrise, the seeder aircraft (under radar control) began seeding. Duration of seeding time varied but averaged about 30 minutes. During this time

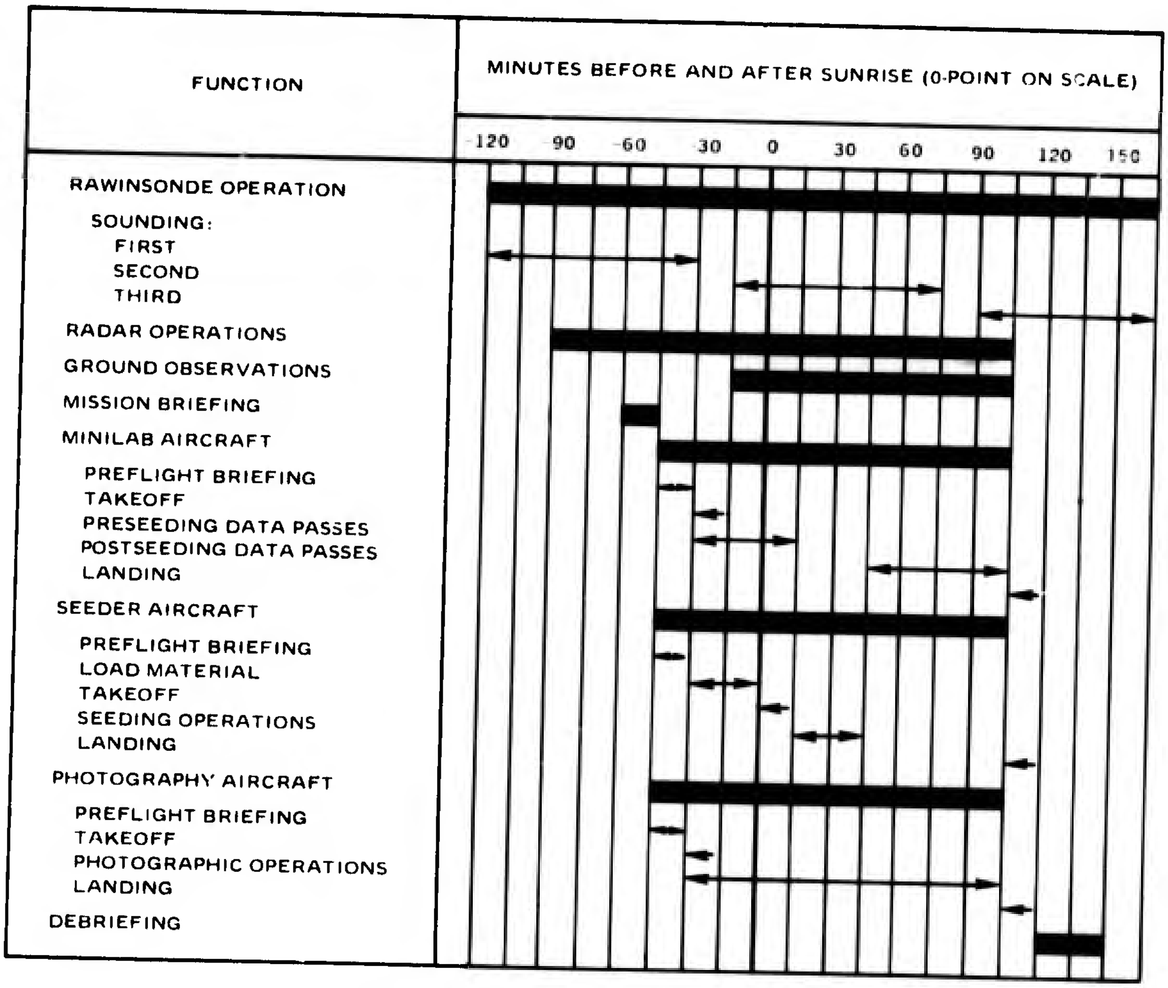

FIG. 21. Standard Operations Schedule.

eight to 10 successive treatments to the fog volume were accomplished.

7. Data collection continued for an hour after the end of seeding, at which time all aircraft returned to base.

8. A postoperations debriefing was held.

In the event that the airport was below minimums (200-foot ceiling and 1/2-mile visibility) at the conclusion of data collection, project aircraft proceeded to alternate airports. The larger seeder aircraft normally selected Redding, whereas the light aircraft landed at Kneeland, an auxiliary airport 10 miles southeast of Arcata. Kneeland, at an altitude of 2,750 feet mean sea level (MSL) is normally well above the coastal stratus. Occasionally, however, as shown in Fig. 22, stratus tops approached or exceeded this altitude, in which case another alternate airport was chosen.

FLIGHT PATTERNS

As mentioned earlier, emphasis during Foggy Cloud III was directed toward improving underlying ceilings and visibilities. To accomplish this goal a "dog-bone" seeding pattern was selected.

FIG. 22. Kneeland Airport, Altitude 2,750 Feet MSL.

Figure 23, which was constructed from radar plots of Test III-16A, shows a seeding pattern but does not show the turnaround parts of the dog-bone pattern. The seeding altitude was normally 500 feet above the fog base, in keeping with that suggested by Ref. 6. This technique, which allows easy pattern adjustment to match the movement of the fog, permits rapid and repeated treatment of a fog volume approaching the airport. During seeding passes the seeder aircraft maintained a speed of 130 knots IAS.

The Minilab aircraft routinely measured fog properties at two altitudes (Fig. 24) over the airport; plans called for at least two preseed and three postseed passes at each altitude. This technique measured fog properties in advance of the seeded volume and permitted a comparison with properties of the seeded volume as it drifted across the airport. This technique assumes that fog properties within the specified area are homogeneous, which, of course, is not always true. A more desirable technique would be to measure fog parameters of the treated volume immediately after *each* pass of the seeding aircraft, but problems of aircraft radar acquisition and aircraft clearance into the control zone precluded using this technique. These data are sorely needed, however, and a set of experiments to provide this quantitative information is currently being planned for Foggy Cloud IV.

Aerial photography was accomplished while flying a track (Fig. 25) identical to that of the Minilab aircraft, but at a standard altitude of 10,000 feet above the fog top. When directly over the middle marker, the T-11 aerial camera was activated, and the pilot maintained level flight, attitude, and heading while flying at 100 knots IAS. With the use of an intervalometer, seven photographs were taken at 20-second

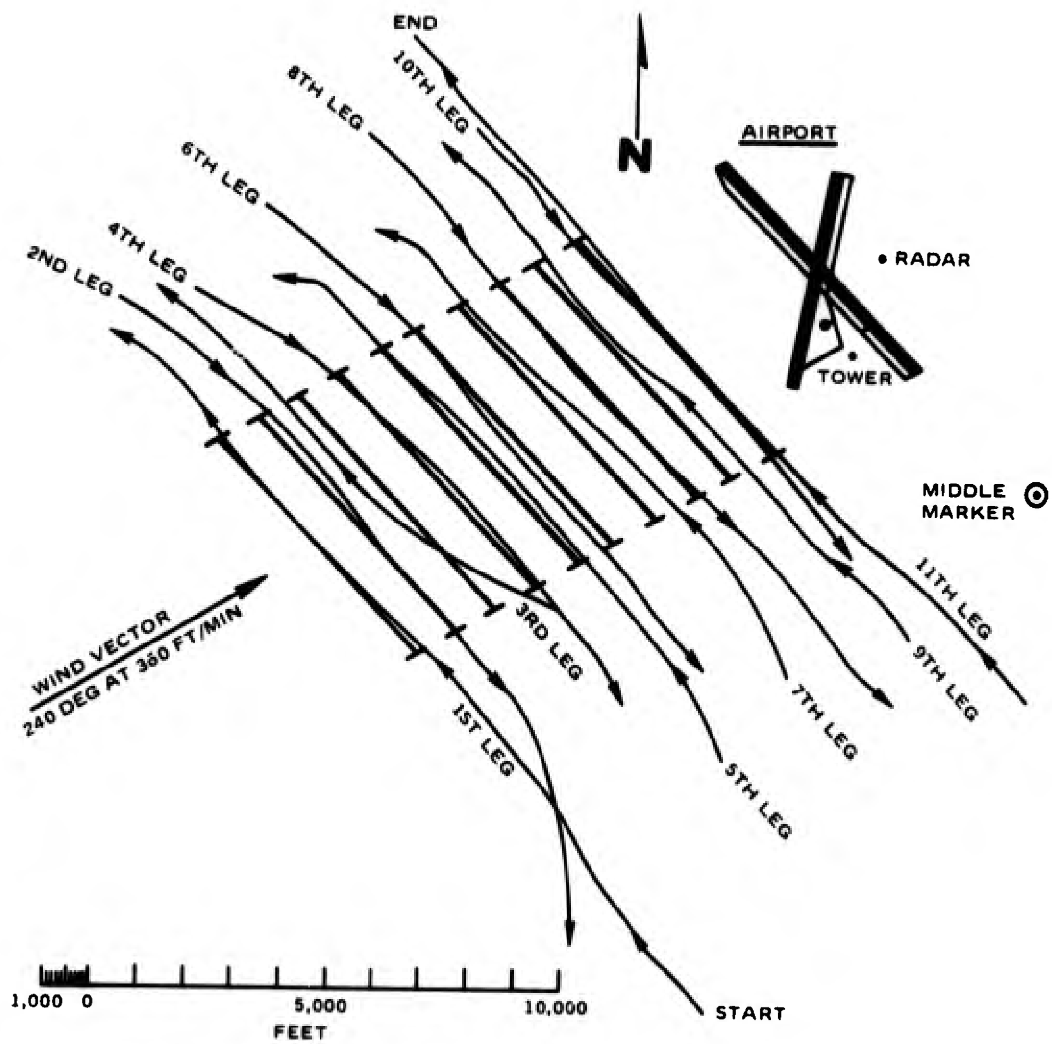

FIG. 23. Radar Plot of Seeding Pattern, Test III-16A, 2 October 1970.

intervals. Passes were made at 6-minute intervals during the period indicated in Fig. 21.

SEEDING AGENT

With the exception of two tests in which tap water was used the project-developed hygroscopic solution of ammonium nitrate, urea, and water was used exclusively. Laboratory data

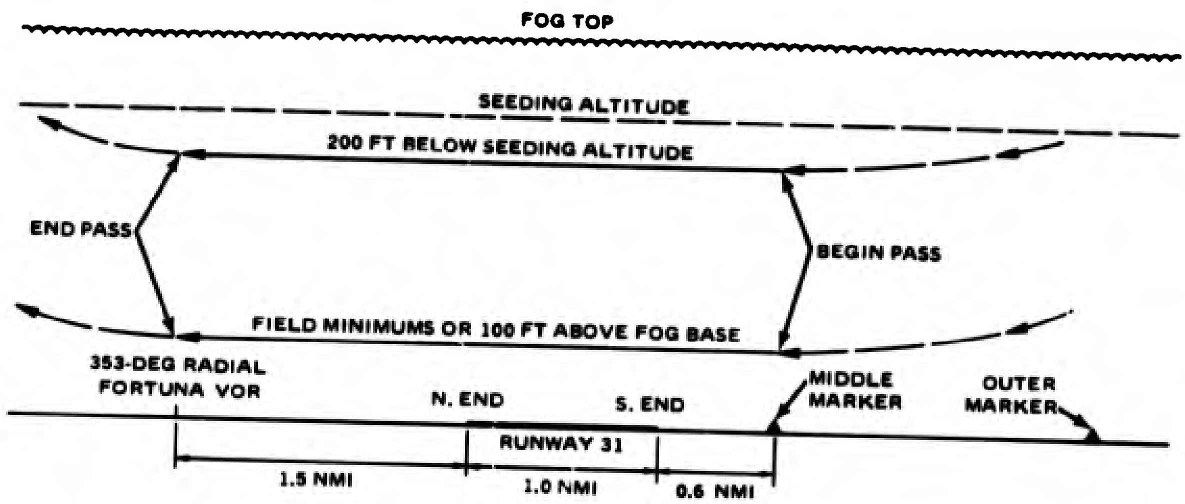

FIG. 24. Minilab Data Passes.

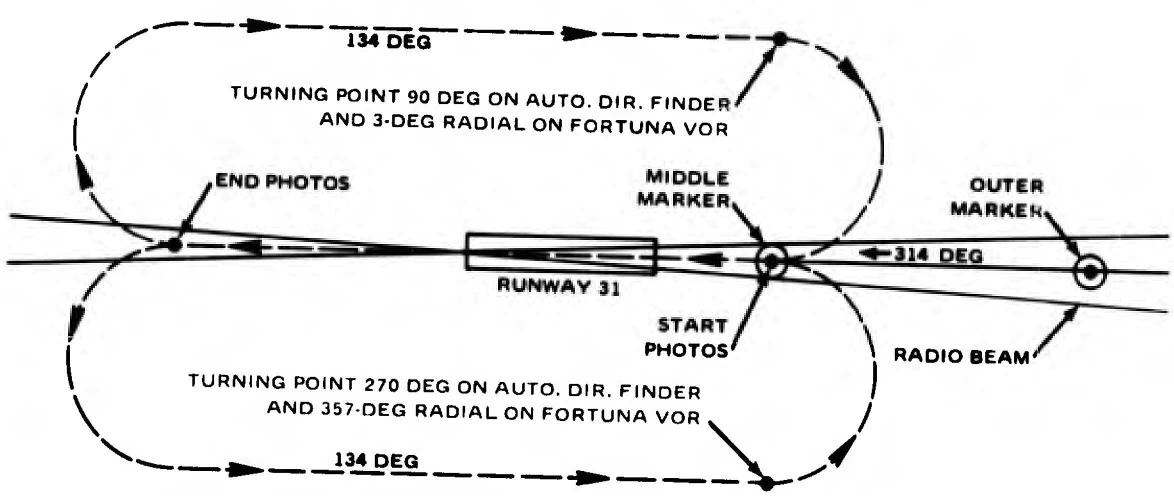

FIG. 25. Photography Aircraft Track at Standard Altitude of 10,000 Feet. Headings shown are magnetic.

concerning composition, liquidus temperature, pH, vapor pressure, density, viscosity, and corrosiveness of various concentrations of equimolar quantities of ammonium nitrate and urea are presented in Tables 3 and 4. These laboratory studies revealed that with proper precautions there should be no deleterious effects, and that, in general, the agent can be described as less corrosive than seawater (Ref. 8).

TABLE 3. Data on the Ammonium Nitrate-Urea-Water System.

Parts solids/ part water, by weight[a]	Composition, moles			Liquidus temperature, °C		pH	Vapor pressure, p		Density (vac) at 26°C, gm/cm³	Viscosity at 26°C, centipoises
	Ammonium nitrate	Urea	Water	Primary	Secondary		mm Hg	°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	1.50	...	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 + 1.33 parts of ammonium nitrate by weight.

TABLE 4. Corrosion of Various Test Materials by an Equimolar Ammonium Nitrate-Urea-Water Solution.

Test specimen	Inhibitor added to solution	Weight loss, gm/cm²/hr × 10⁶
Magnesium alloy, AZ31B[a]	None	738
	1.6% thiourea and 0.8% K_3PO_4	1114
Brass	None	111
	1% thiourea	8
Mild steel	None	28
	1% thiourea	0.45
Chromium plated[b] steel	None	1.3
	1% thiourea	4.7
Cadmium plated[c] steel	None	247
Aluminum	None	0
	1% thiourea	0
Lacquers and enamels ...	None	No visible effects

[a] For tests with magnesium, the solution was diluted to 60%, the dilution in which the greatest loss occurs.
[b] 0.01 mil thick.
[c] 0.5 mil thick.

TREATMENT DENSITY

Both the B-26 and the DC-7 seeder aircraft were equipped with standard agriculture spray nozzles (Spraying Systems Co., Type 2515). Nozzle orifices were oval-shaped, with dimensions of 0.8 by 0.15 inch. As previously stated, the B-26 had 92 nozzle positions; however, only 86 were used. The DC-7 had 150 nozzle positions but was equipped with only 100 nozzles.

Delivery rates varied somewhat. However, for an approximation of treatment densities, flow rates of 250 and 450 gal/min, respectively, for the B-26 and the DC-7 were used. For (1) a volume measuring 2,000 by 60 (B-26 swath) by 150 meters, (2) a total treatment of 1,000 gallons of hygroscopic agent, and (3) an airspeed of 130 knots, a total of eight 2,000-meter-long passes at 125 gal/pass would be made, with a treatment density of 0.035 g/m^3/pass and a total treatment density of 0.28 g/m^3. This calculation fails to give consideration to pilot and aircraft response under radar control or to diffusion of the dispensed solution. Experience has shown that a 300-meter instead of a 60-meter swath width is a more realistic width to use in calculations of treatment density. Using this dimension, a treatment density of 0.007 g/m^3/pass and a total treatment density of 0.056 g/m^3 are realized. This treatment agrees reasonably well with that suggested in Ref. 6. For the same seeding techniques and with the same swath width as used by the B-26, the DC-7 treatment values per pass are approximately doubled, and the total treatment possible increased threefold.

SURFACE OBSERVATIONS

The ground observer stationed in the tower performed a set of observations at 10-minute intervals. These observations included:

1. Fixed-position 35-mm still photography
2. Exposure of urea-sensitive paper
3. Weather observations of ceiling, visibility, wind, temperature, and dew point
4. Two-minute exposures of gelatin-coated slides

Urea-sensitive paper was exposed as an aid in verifying the accuracy of targeting. A urea reaction (color change) was taken as evidence of accurate targeting, and in most cases this effect was observed. The absence of a reaction, although certainly making the targeting suspect, did not necessarily mean that targeting was poor. With seeding accomplished upwind and maximum effects planned to occur over the airport, a relatively dry volume with few, if any, precipitating droplets might well be experienced.

Gelatin-coated slides were exposed to measure fallout droplet count, size, and distribution. Information concerning slide preparation, decay, and data reduction is contained in Ref. 1.

EXPERIMENTAL DATA

DATA COLLECTION AND REDUCTION

As indicated in the foregoing sections, a wide range of data was collected from various sources during Phase I. Principal data collected are listed in Table 5.

TABLE 5. Principal Data and Source.

Note: "a" entries mean aloft and "s" entries mean surface.

Type of data	Source									
	Rawin-sonde	Minilab	Observer plane	Seeder plane	Photo-graphy plane	Radar	Ground observer	Nat. weather facsimile	Flight service station	NBS transmis-someters
Fog top	a	a	a	a	a	...	...	...	...	...
Fog type	a	a	a	...	...	...	s	...	s	...
Areal extent of fog	...	...	a	...	a	...	...	...	...	..
Wind	a	...	...	...	...	...	s	...	s	...
Pressure	a	a	...	...	...	...	...	...	s	...
Temperature	a	a	..	...	...	...	s	...	s	...
Dew point	a	a	...	...	...	...	s	...	s	...
Liquid water content	...	a	...	...	...	...	...	...	...	...
Particle size and distribution	...	...	...	...	...	...	s	...	...	...
Transmissivity	...	...	...	...	...	...	...	...	s	s
Photographs	...	...	a	...	a	...	s	...	...	...
Ceiling and visibility	...	...	...	...	...	...	s	...	s	...
Precipitation type and amount	...	a	...	...	...	...	s	...	s	...
Standard weather charts	...	...	...	...	...	...	...	sa	...	...
Seeding material	...	...	...	a	...	...	...	...	...	...
Seeding technique	...	...	...	a	...	a	...	...	...	...
Visual observations	...	a	a	a	a	...	s	...	s	...

Preprinted special project data logs and forms were completed by all ground and airborne project personnel; samples of these forms are appended to the Experimental Plan 2-70.[1] Pertinent data from these sources, as well as instrument recordings and Minilab computer print-outs, were extracted and summarized on site. Figure 26 shows a Minilab single-pass print-out and plot from Test III-9A. A tabulation of test data collected and on file at NWC is included as Appendix A.

ANALYSIS AND REPORTING

After data had been reduced, it was a simple task to conduct a preliminary analysis. Key trends expected if fog abatement was successful were

1. An increase in ceiling
2. An increase in visibility
3. An increase in transmissivity
4. A decrease in droplet count
5. An increase (possibly) in droplet size
6. A decrease in liquid water content (LWC)
7. An increase in temperature
8. A decrease in relative humidity

Biweekly progress reports were sent to sponsors during Phase I. These included preliminary analysis of tests conducted, project problem areas, and project plans.

AIRCRAFT DATA REDUCTION DATE - 25 8 1970 225 METRO DATA PAGE 10

TIME, HR, MIN, SEC	PRES ALT., FT MSL	PRESSURE, MB	TRUE AIR SPEED, KNOTS	TEMPERA-TURE, °C	DEW POINT, °C	RELATIVE HUMIDITY, %	LWC, G/M^3	MEAN GUST VELOCITY, M/SEC
			OVER MIDDLE MARKER					
100734	447	998	116	10.4	9.9	96.9	.08	.44
100735	447	998	117	10.3	9.9	97.4	.08	.48
100737	447	998	117	10.3	9.9	97.3	.04	.52
100739	447	998	115	10.4	9.9	97.0	.04	.53
100741	459	998	117	10.4	9.7	95.6	.04	.53
100742	465	996	118	10.3	9.9	97.3	.02	.52
100744	456	998	118	10.3	9.9	97.3	.06	.54
100746	447	998	117	10.4	9.9	96.7	.07	.60
100748	447	998	115	10.5	9.9	96.3	.07	.65
100749	447	998	116	10.6	9.9	95.7	.03	.64
			OVER SOUTH END OF RUNWAY					
			PARTIAL PASS AVERAGE					
	450.9	997.8	116.8	10.40	9.89	96.75	.05	.54
100752	447	998	118	10.5	10.0	96.9	.02	.63
100754	447	998	119	10.5	10.0	97.1	.08	.69
100756	438	998	121	10.4	10.0	97.2	.06	.76
100758	420	999	122	10.3	10.0	98.1	.10	.84
100800	411	999	122	10.2	9.8	97.5	.11	.87
100802	411	999	122	10.2	9.8	97.4	.09	.84
100803	411	999	121	10.2	9.8	97.5	.10	.87
100805	411	999	121	10.1	9.7	97.2	.11	.87
100807	411	999	119	10.1	9.7	97.3	.11	.89
100808	417	999	119	10.1	9.7	97.6	.14	.91
100810	438	998	120	10.0	9.6	97.6	.13	.91
100812	447	998	119	10.0	9.6	97.5	.11	.97
100813	441	998	121	9.8	9.4	97.5	.16	.99
100815	429	999	120	9.8	9.4	97.7	.14	1.00
100817	438	998	121	9.7	9.3	97.5	.18	.95
100819	447	998	120	9.7	9.4	98.3	.16	.92
100820	447	998	119	9.7	9.3	97.5	.14	.86
			OVER NORTH END OF RUNWAY					
			PARTIAL PASS AVERAGE					
	430.1	998.5	120.4	10.02	9.64	97.55	.12	.87
100822	447	998	120	9.6	9.3	97.9	.20	.76
100824	447	998	119	9.6	9.3	98.1	.16	.72
100826	447	998	119	9.5	9.1	97.1	.14	.71
100828	447	998	120	9.5	9.1	97.3	.14	.71
100830	447	998	122	9.5	9.2	97.9	.13	.70
100831	447	998	122	9.5	9.1	97.1	.14	.63
100833	447	998	123	9.5	9.2	97.8	.12	.61
100835	447	998	123	9.5	9.1	97.2	.13	.60
100836	447	998	123	9.6	8.6	93.7	.13	.60
100838	447	998	123	9.6	9.2	97.6	.12	.63
100840	447	998	123	9.5	9.2	97.8	.14	.64
100841	447	998	123	9.5	9.1	97.2	.15	.63
100843	447	998	122	9.6	8.8	95.1	.14	.65
100845	447	998	119	9.6	9.0	95.9	.15	.65
100846	447	998	121	9.6	9.2	97.4	.14	.66
100848	447	998	120	9.6	8.5	93.3	.14	.65
100850	447	998	120	9.5	9.2	98.3	.14	.65
100852	447	998	122	9.5	9.0	97.0	.14	.69
100853	447	998	124	9.4	9.4	100.0	.16	.72
100855	447	998	125	9.4	9.2	98.9	.16	.80
100858	436	998	125	9.3	8.7	96.1	.17	.83
100900	417	999	125	9.3	9.1	98.9	.16	.88
100901	411	1000	125	9.2	9.2	99.9	.17	.85
100903	411	1000	123	9.3	9.1	98.9	.16	.80
100905	411	1000	122	9.2	9.1	99.1	.17	.78
			END OF DATA PASS NO. 2					
			PARTIAL PASS AVERAGE					
	441.0	998.3	122.2	9.47	9.07	97.44	.15	.70

(a) Computer print-out.

FIG. 26. Minilab Data From Test III-9A.

P ALT MSL

1800

1600

1400

1200

1000

800

600

400

200

START FOGGY

13

DATA PAGE 10

MEAN
GUST
VELOCITY,
M/SEC

.44
.48
.52
.53
.53
.52
.54
.60
.65
.64

.54
.63
.69
.76
.84
.87
.84
.87
.87
.89
.91
.91
.97
.99
1.00
.95
.92
.86

.87
.76
.72
.71
.71
.70
.63
.61
.60
.60
.63
.64
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.72
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.83
.88
.85
.80
.73

.70

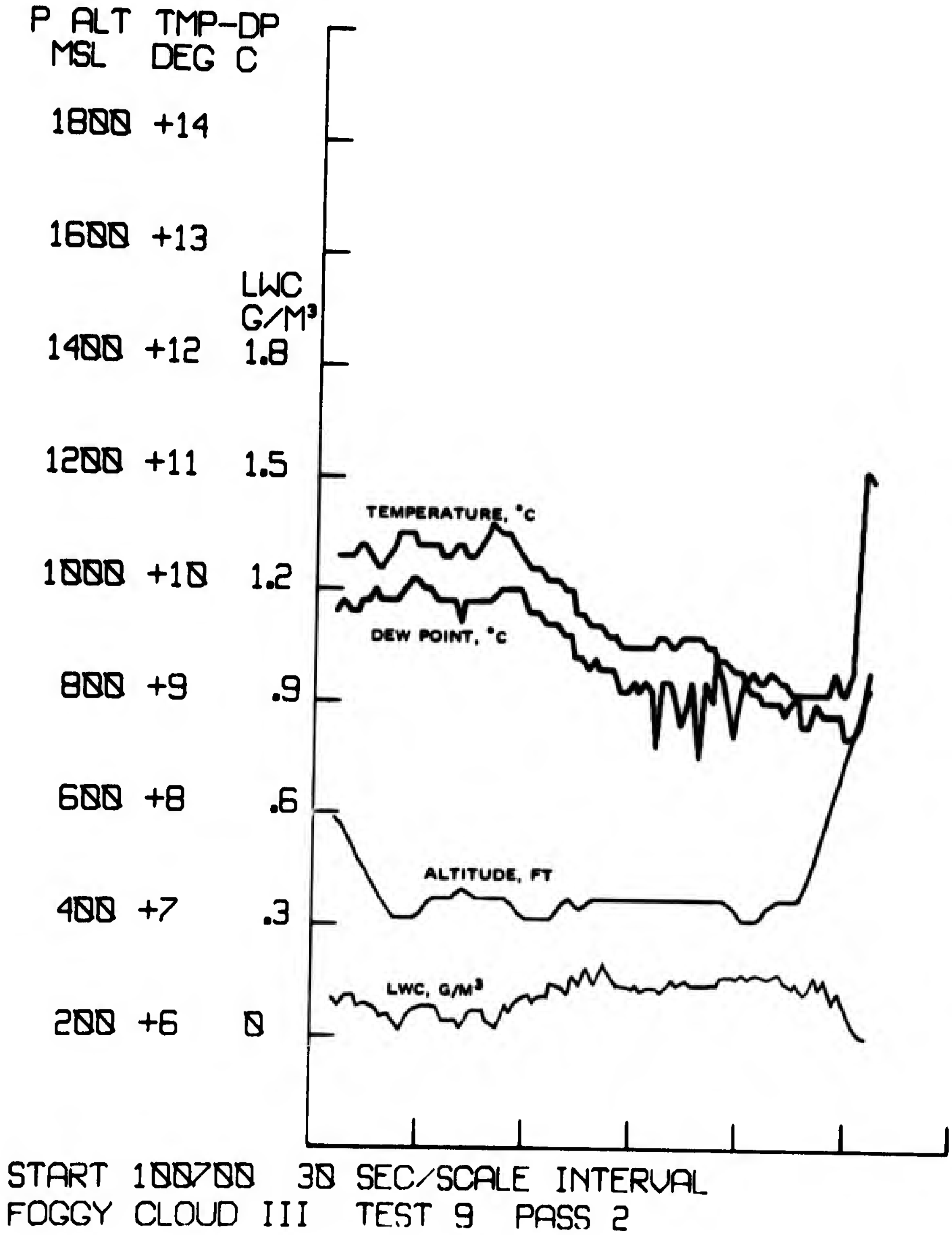


FIG. 26. Minilab Data From Test III-9A.

(b) Corresponding computer plot.

TEST RESULTS

SUPPORT TESTS

In addition to the 19 seeding tests, support tests were also conducted to gather background information relative to fog properties, formative processes, and behavioral patterns and to provide data pertinent to seeder aircraft spray systems, such as flow rates, swath widths, and droplet size and distribution. Results of these tests will be published as special studies. A table of support tests conducted is included as Appendix B.

SELECTED TESTS

Five selected tests are described in detail. Criteria for test selection were (1) relatively stable fog conditions, (2) in-fog seeding upwind or over the airport with 9:1 solution, and (3) reasonable operations precision. Also included is a single pulsed-seeding test (III-12A), so-termed because the hygroscopic solution was intermittently introduced from a position fixed with respect to the ground rather than into the same portion of fog, and hence it tended to arrive at the target in pulses rather than in a continuous, relatively narrow band. The effects of pulsed seeding were pronounced, which raised the question of the optimum treatment dosage.

A visibility reference photograph (Fig. 27) is provided as an aid in viewing selected test photographs.

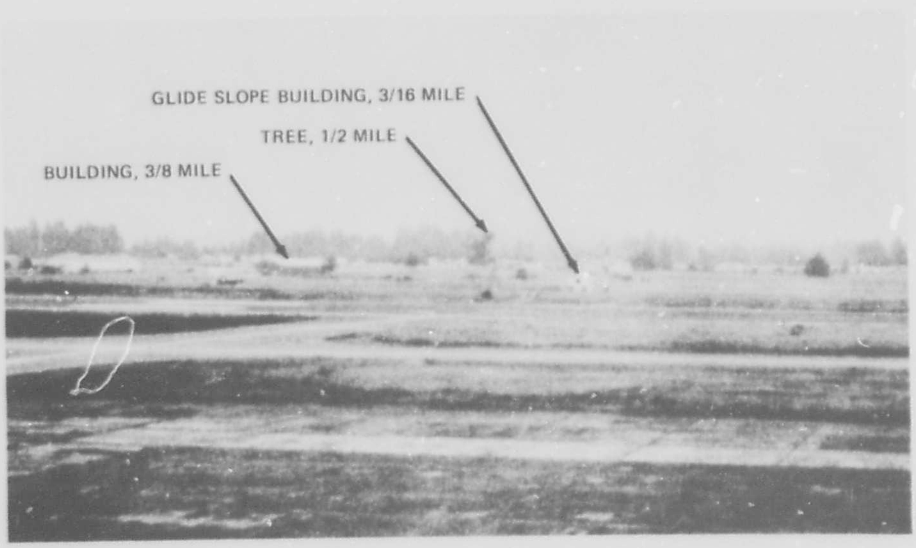


FIG. 27. Visibility Reference Photograph.

Test III-4A, 27 July

The test design for the seeding aircraft was as follows:

Aircraft B-26
Speed, knots IAS 130
Altitude, ft AGL 700
Flight pattern .... dog-bone

Passes:
No. 7
Duration, sec 30

Solution:
Ratio 9:1
Amount, gal 1,000
Spray rate, gal/min 300
No. of nozzles 86

Time of seeding:
Begin 0722
End 0734

Fog Conditions and Surface Observations. Fog had developed over the airport at 0500 and reached its peak intensity at 0630, with ceiling zero and visibility 1/8 mile. By seeding time conditions had improved and stabilized at ceiling 200 feet AGL, and visibility 1/2 mile. Tops were reported at 1,600 feet AGL. Figure 28 depicts atmospheric conditions 33 minutes before seeding began. Winds were light westerly, with a targeting vector wind of 261 degrees at 3 knots.

With the light wind regime, seeding was conducted close to the airport and effects from seeding were noted before the final seeding pass. The clearing pulse peaked 6 minutes after seeding ended at ceiling 300 feet AGL, visibility 1 mile (Fig. 29). Conditions then deteriorated below their initial value. Duration of improved conditions was 20 to 30 minutes. Transmissometer readings on runway

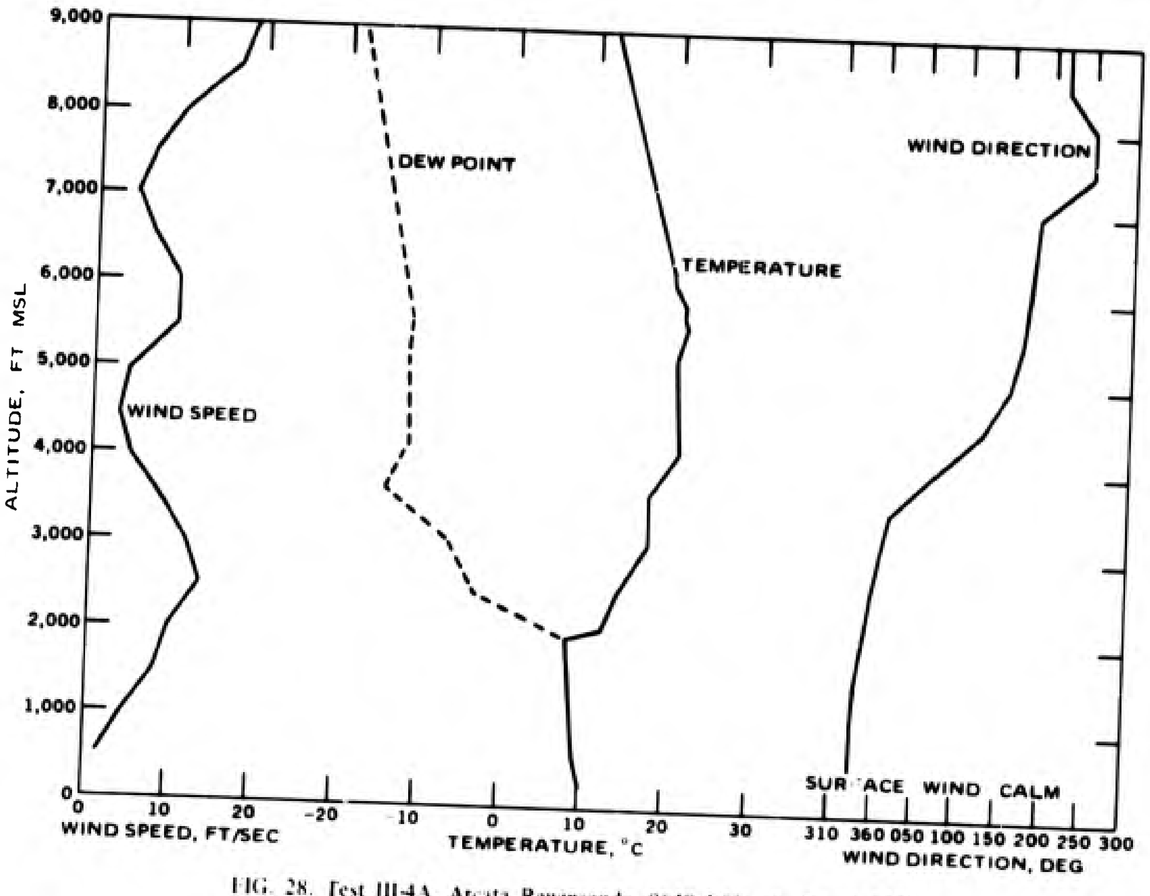


FIG. 28. Test III-4A, Arcata Rawinsonde, 0648 LST, 16 August 1970.

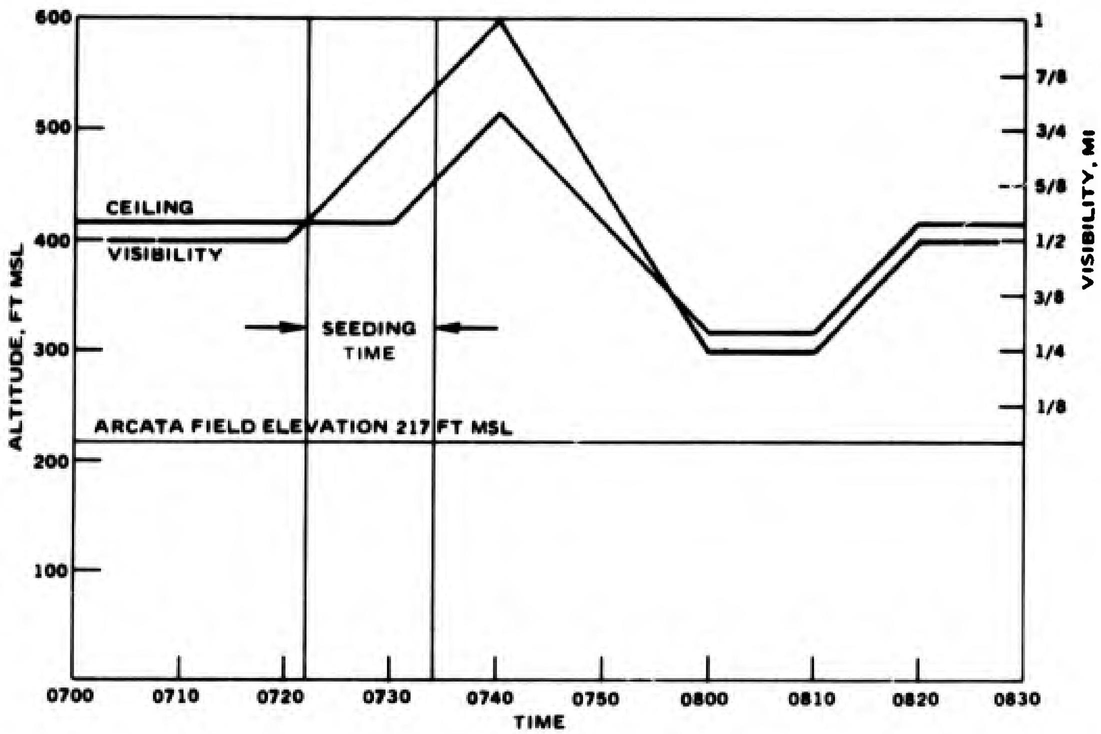


FIG. 29. Test III-4A, Ceiling and Visibility.

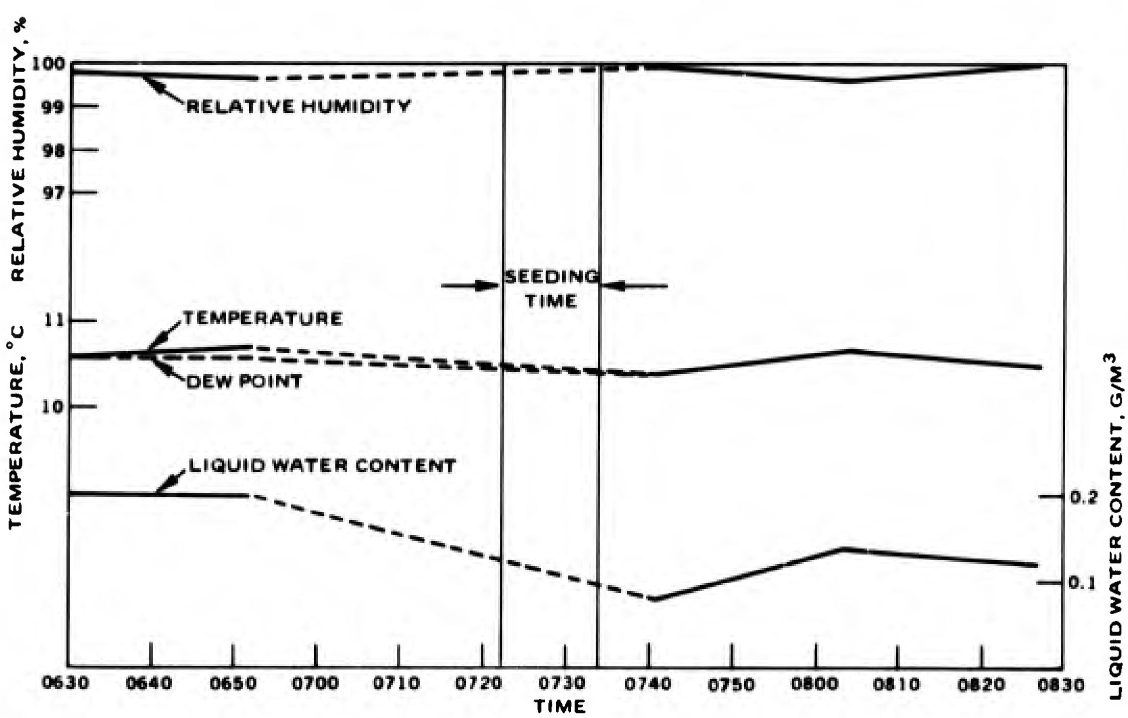
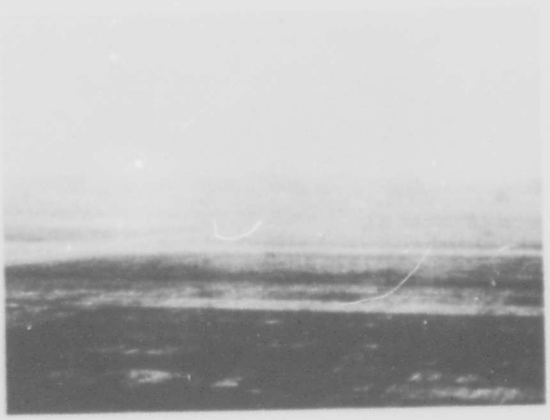


FIG. 30. Test III-4A, Average Pass Values From South End to North End of Runway 31. Pass altitudes were 600 feet MSL ± 60 feet, 300 feet below seeding altitude. Where dashed lines are shown, no data were taken.

visual range (RVR) were erratic with readings of 6,000+ feet during the entire test period. It has been found that when visibility approaches 1 mile, transmissometer measurements are questionable.

Airborne Observations. Except for a decrease of 0.12 g/m^3 in LWC (Fig. 30), Minilab measurements failed to reflect the clearing. Values of temperature, dew point, and relative humidity remained nearly constant. The need for continuous, in-cloud data collection is obvious.

Photography. With seeding at 700 feet AGL and the fog top at 1,600 feet AGL, aerial photography did not reflect the effects of seeding. Changes to underlying surface conditions, however, were photographically documented and are shown in Fig. 31.



(a) Two minutes before seeding began.

(b) Four minutes before seeding ended.

(c) Six minutes after seeding ended.

(d) Twenty-six minutes after seeding ended.

FIG. 31. Test III-4A, Surface Conditions Before and After Seeding.

Test III-5A, 18 August

The test design for the seeding aircraft was as follows:

Aircraft B-26
Speed, knots IAS 130
Altitude, ft AGL 700
Flight pattern .... dog-bone

Passes:
- No. 8
- Duration, sec 25

Solution:
- Ratio 9:1
- Amount, gal 1,000
- Spray rate, gal/min 300
- No. of nozzles 86

Time of seeding:
- Begin 0942
- End 1005

Fog Conditions and Surface Observations. Test conditions were similar to those in III-4A. Fog began forming over the airport at 0400 and reached a peak intensity at 0715, when the field went below minimums (200-foot ceiling AGL and 1/2-mile visibility) for a short time. From 0730 to seeding time, 0942, conditions stabilized at ceiling 200 feet AGL, visibility 1/2 to 3/4 mile. Tops were 900 feet AGL. Figure 32 depicts atmospheric conditions about 1 hour before seeding began. At seeding time, winds had shifted somewhat from those shown and a vector wind of 233 degrees at 2 knots was computed for targeting.

Ceiling and visibility began improving about 10 minutes after seeding began (Fig. 33), reaching a peak improvement 15 minutes after seeding with ceiling 500 feet AGL, and visibility 2 miles. Deterioration followed, with conditions returning to near their original state about 35 minutes after

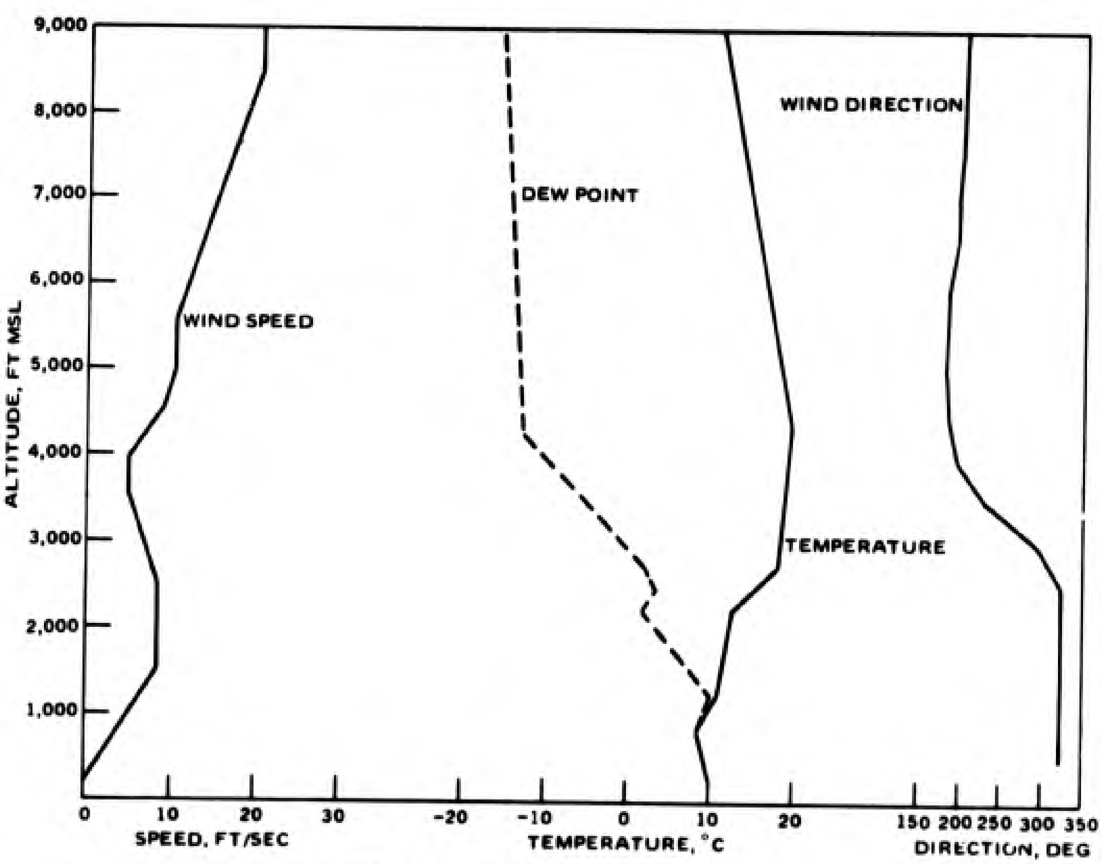


FIG. 32. Test III-5A, Arcata Rawinsonde, 0832 LST, 18 August 1970.

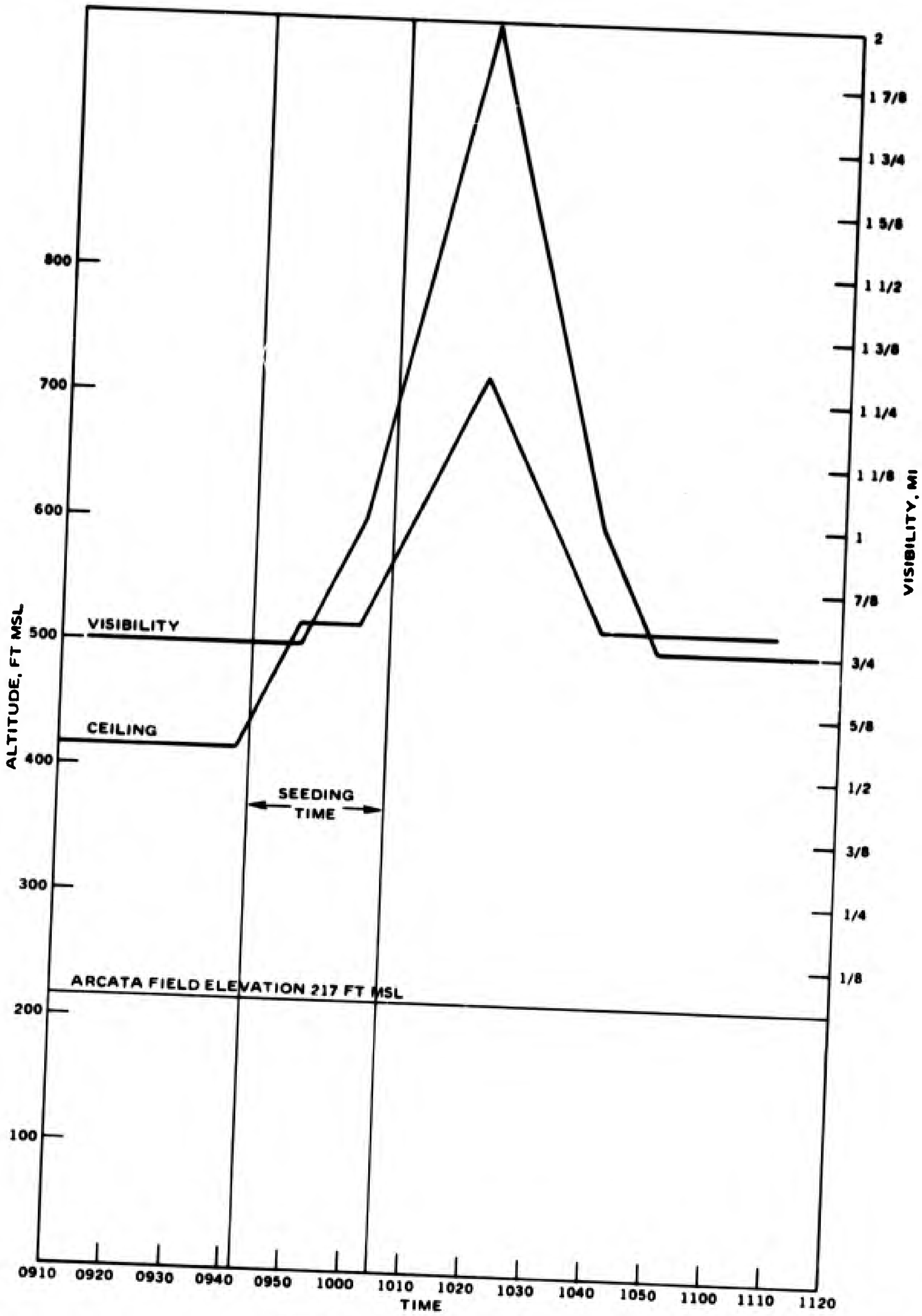


FIG. 33. Test III-5A, Ceiling and Visibility.

seeding ended. Once again, transmissometer records were erratic. An abrupt rise from RVR 3,400 feet to RVR 6,000+ feet at 1010 was noted. Surface droplet sampling showed a wide variation in median size. Droplet count, however, did show an abrupt decrease to near zero, 18 minutes after seeding began.

Airborne Observations. Minilab plots are shown in Fig. 34. Values and trends indicated are certainly in keeping with those hoped for. A temperature rise of 1°C, relative humidity drop of 2%, and LWC decrease of 0.11 g/m^3 are all indicative of the decrease in fog density.

Photography. With seeding accomplished only 200 feet below fog-top, it was hoped that on-top effects might be observed and documented with the aerial camera. Such was not the case, however, as tops remained solid and intact throughout the test period. Fixed-position surface photography, however, did reflect changes in ceiling and visibility as shown in Fig. 35.

Special Observations. A laser (light detection and ranging, LIDAR) borrowed from Stanford Research Institute was made available to the project for a few days and was in operation during this test. Following the test, Dr. R. A. Roberts, the scientist who operated the LIDAR, issued a statement as to the LIDAR's effectiveness. An extract from that statement is as follows: "During Foggy Cloud III a borrowed laser (LIDAR) was used during one test to study the effect of seeding. The laser beam was directed vertical to the airport runway and the fog-scattered return observed. A dramatic change in visibility was recorded after seeding was begun. In addition, the seeded volume was tracked as it moved under the effect of the wind. The LIDAR is extremely valuable in recording instantaneous visibility along any path and provides a new and better method for directing reseeding runs by following the seeded volume." Current project planning for Foggy Cloud IV incorporates further use of the LIDAR.

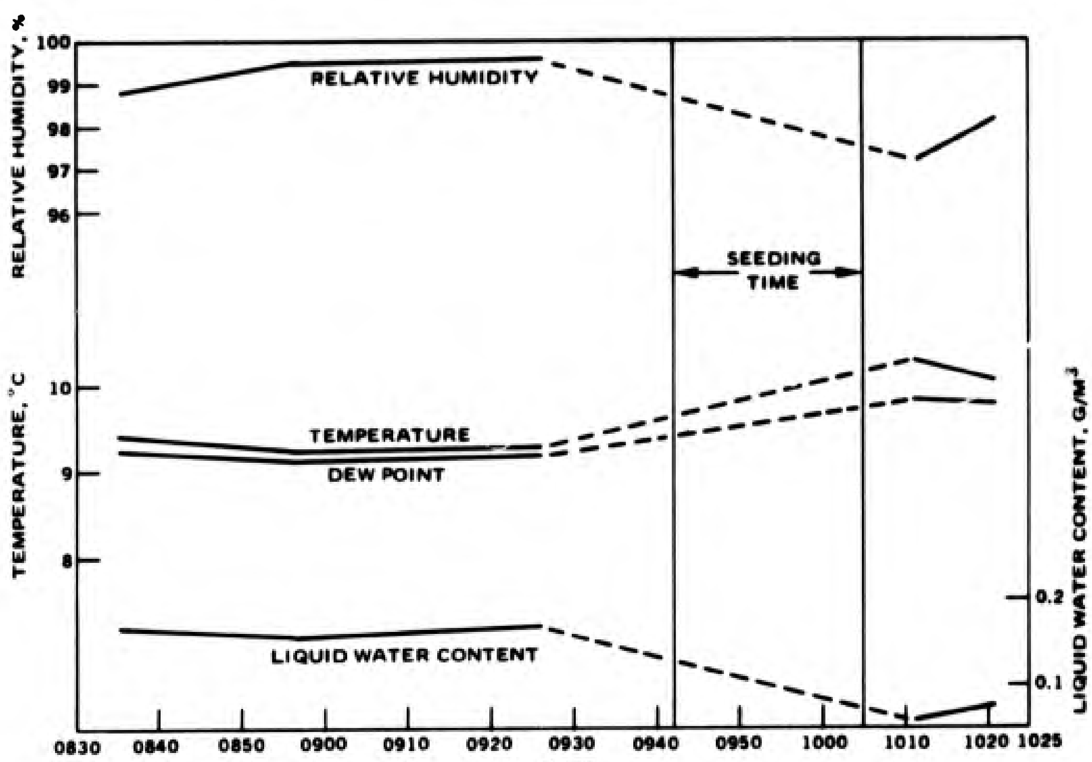
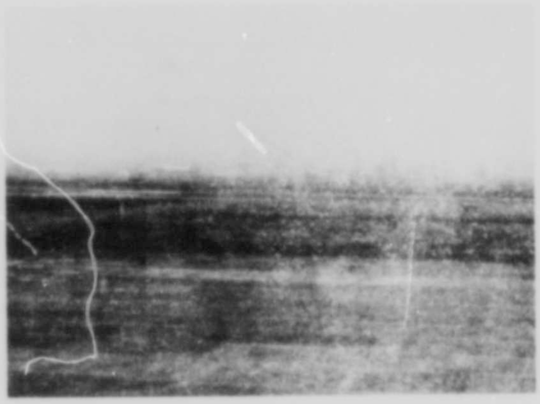


FIG. 34. Test III-5A. Average Pass Values From South End to North End of Runway 31. Pass altitudes were 600 feet MSL ± 60 feet, 300 feet below seeding altitude. Where dashed lines are shown, no data were taken.

(a) Two minutes before seeding began.

(b) Five minutes before seeding ended.

(c) Fifteen minutes after seeding ended.



(d) Twenty-five minutes after seeding ended.

FIG. 35. Test III-5A, Surface Conditions Before and After Seeding.

Test III-12A, 29 August

The test design for the seeding aircraft was as follows:

Aircraft	B-26
Speed, knots IAS	130
Altitude, ft AGL	700
Flight pattern	dog-bone
Passes:	
No.	9
Duration, sec	27

Solution:	
Ratio	9:1
Amount, gal	1,000
Spray rate, gal/min	245
No. of nozzles	76
Time of seeding:	
Begin	1002
End	1025

Fog Conditions and Surface Observations. Test III-11A on 29 August (see Test Summary) was a three-phase, pulsed water test with the DC-7 as the seeder. After the fog had once again stabilized, Test III-12A was conducted in an effort to compare the effects of the 9:1 solution with those of water. In order to draw a comparison it was necessary that Test III-12A also employ a pulsed spray pattern. With a relatively high wind condition, vector wind 240 degrees at 9 knots, a dog-bone pattern was laid out 1-1/2 miles upwind, paralleling Runway 31. Nine 27-second spray passes were accomplished in 23 minutes.

At the onset of seeding, conditions were reported as ceiling 100 feet AGL, visibility 3/8 mile. Atmospheric conditions are shown in Fig. 36. About 5 minutes before seeding ended, the first improvement was noted. This trend continued, sharply peaking out about 15 minutes after seeding ended with ceiling 300 feet AGL, visibility 1 mile. Thereafter, conditions returned to their original state. Figure 37 depicts ceiling and visibility during the test period. The official transmissometer gave RVR measurements (Fig. 38), which reflected the clearing.

An analysis of median droplet size and relative count is shown in Fig. 39. Median size, which had been constant at ~21 microns (μ) both before and during seeding, shifted to ~31 μ 5 minutes after seeding ended. Droplet count, which was increasing as seeding began, made a trend reversal 8 minutes after seeding began, reaching its lowest value 5 minutes after seeding ended.

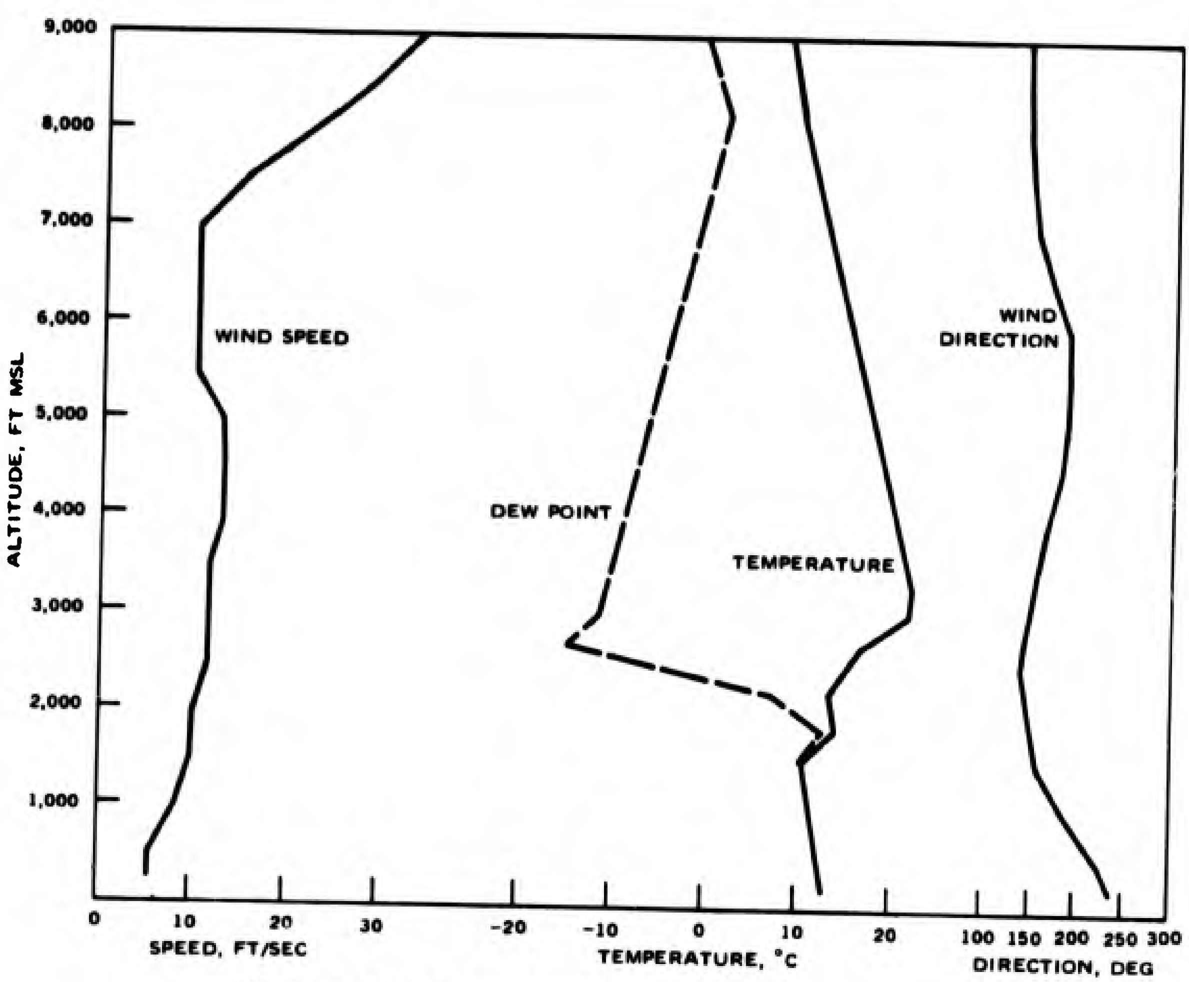


FIG. 36. Test III-12A, Arcata Rawinsonde, 0642 LST, 29 August 1970.

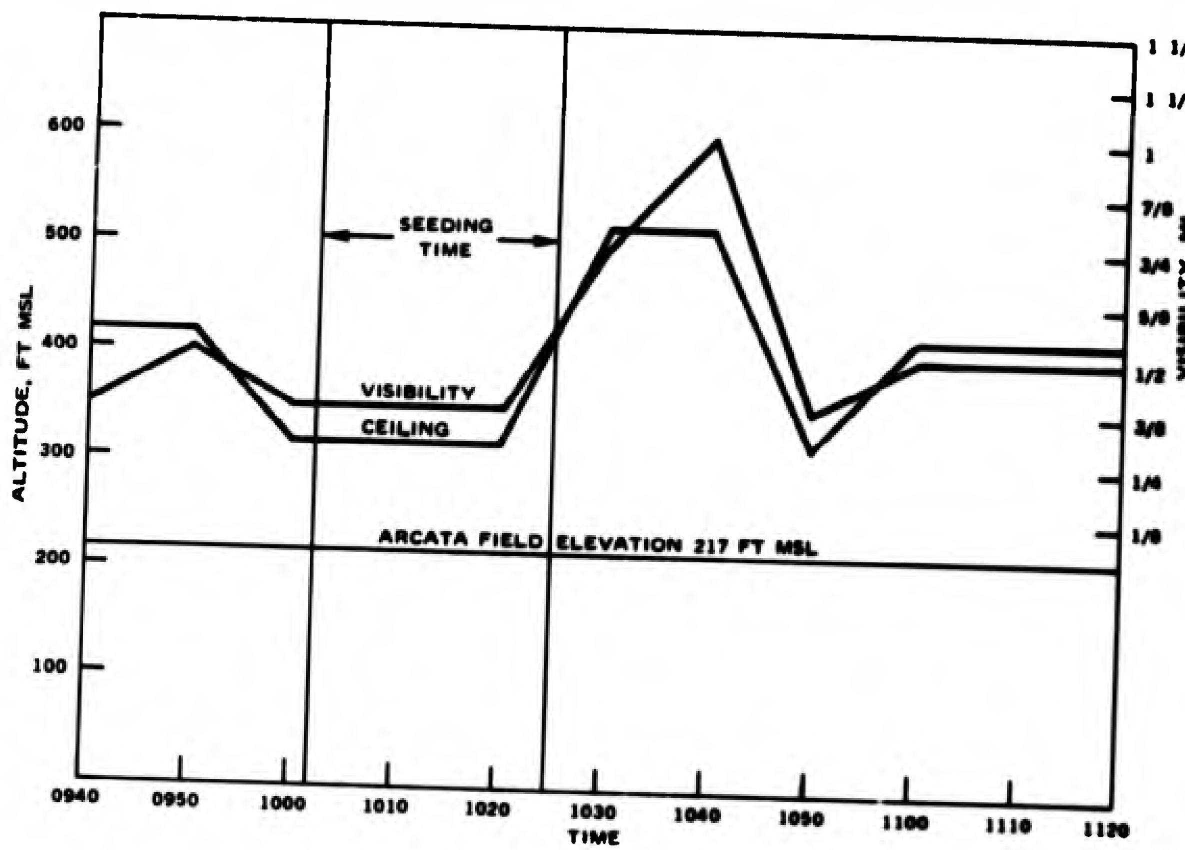


FIG. 37. Test III-12A. Ceiling and Visibility.

The results of this test raised questions about the treatment density required for successful fog clearance.

Airborne Observations. The Minilab was out of commission on this test.

Photography. Fixed-position surface photography (Fig. 40) documented the observed clearing.

Test III-15A, 28 September

The test design for the seeding aircraft was as follows:

Aircraft	B-26
Speed, knots IAS	130
Altitude, ft AGL	500
Flight pattern	dog-bone
Passes:	
No.	10
Duration, sec	26
Solution:	
Ratio	9:1
Amount, gal	1,000
Spray rate, gal/min	230
No. of nozzles	86
Time of seeding	
Begin	0946
End	1020

Fog Conditions and Surface Observations. This was a very dense fog that had developed over the airport near midnight, and the field had been closed to flight operations during the entire period. A Phase II helicopter test preceded III-15A. Tops of the fog were at 750 feet AGL. Figure 41 depicts conditions for this date. While surface winds were near calm, the vector wind computed near seeding time was 251 degrees at 11 knots. Ceiling and visibility were zero and 1/16 mile. These

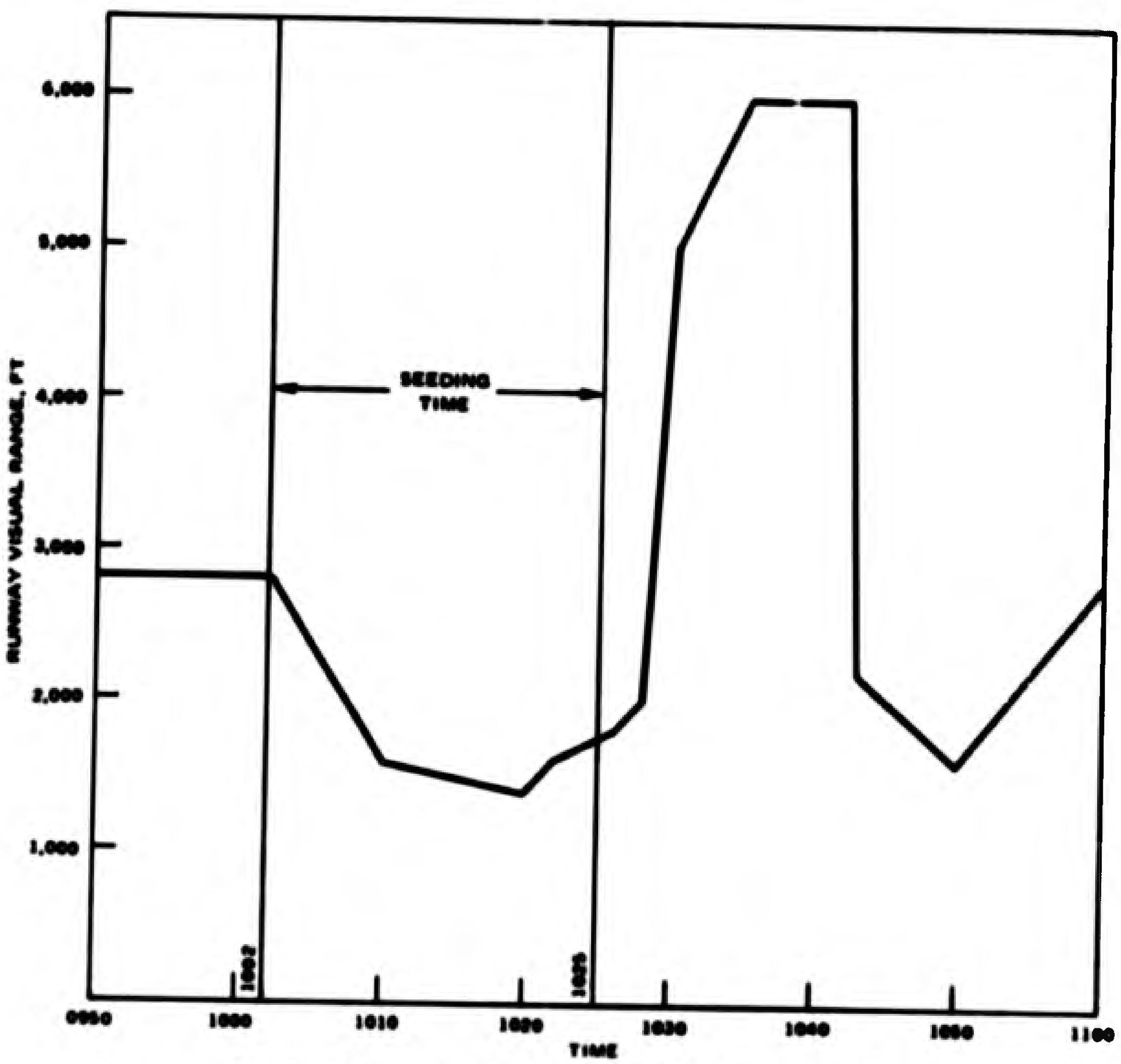


FIG. 38. Test III-12A. Runway Visual Range From Transmissometer.

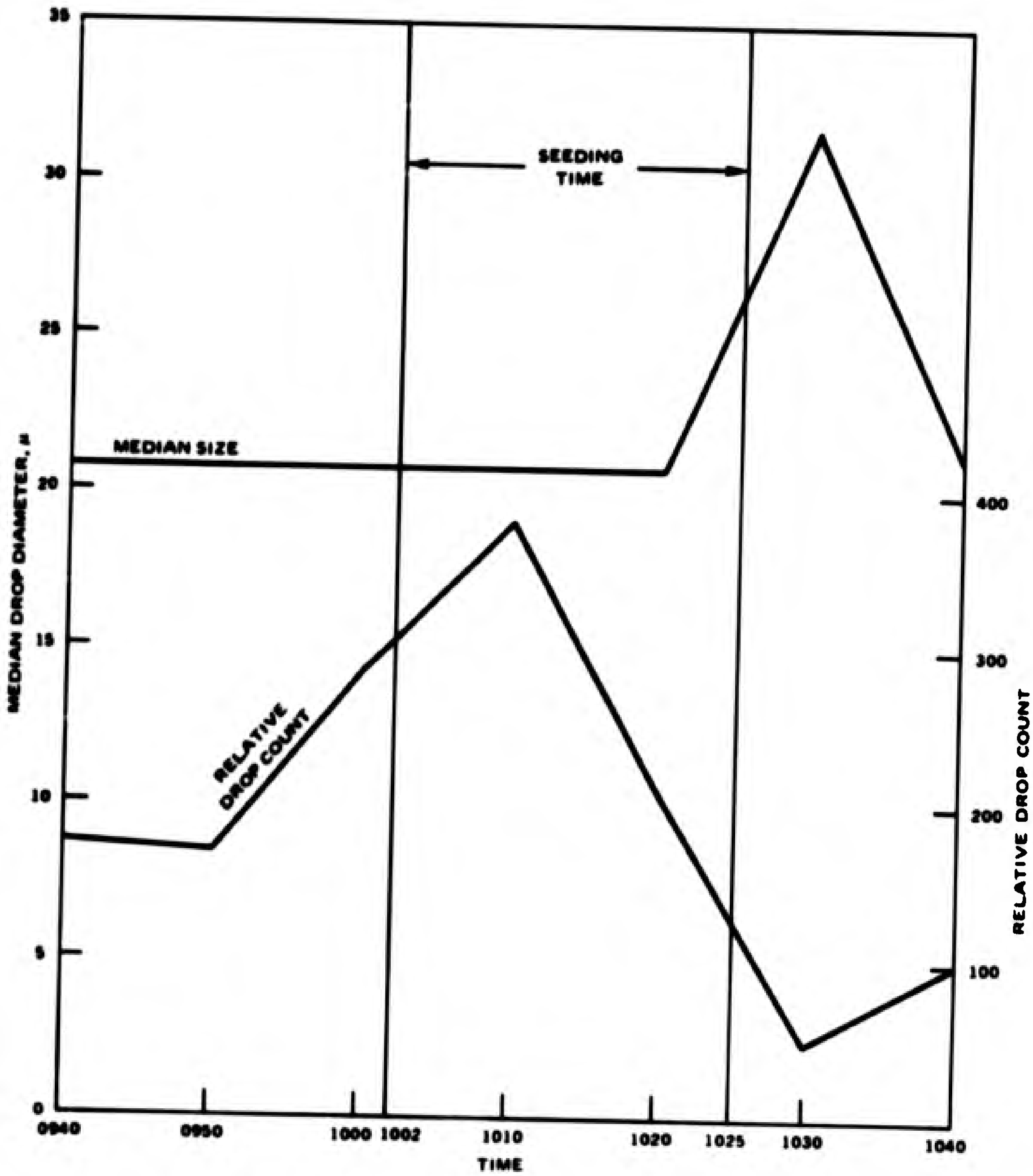
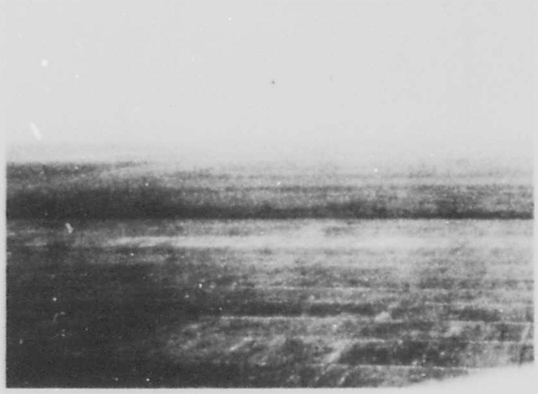


FIG. 39. Test III-12A, Relative Drop Count and Median Size.

(a) Two minutes before seeding began.



(b) Five minutes before seeding ended.

(c) Five minutes after seeding ended.

(d) Twenty-five minutes after seeding ended.

FIG. 40. Test III-12A, Surface Conditions Before and After Seeding.

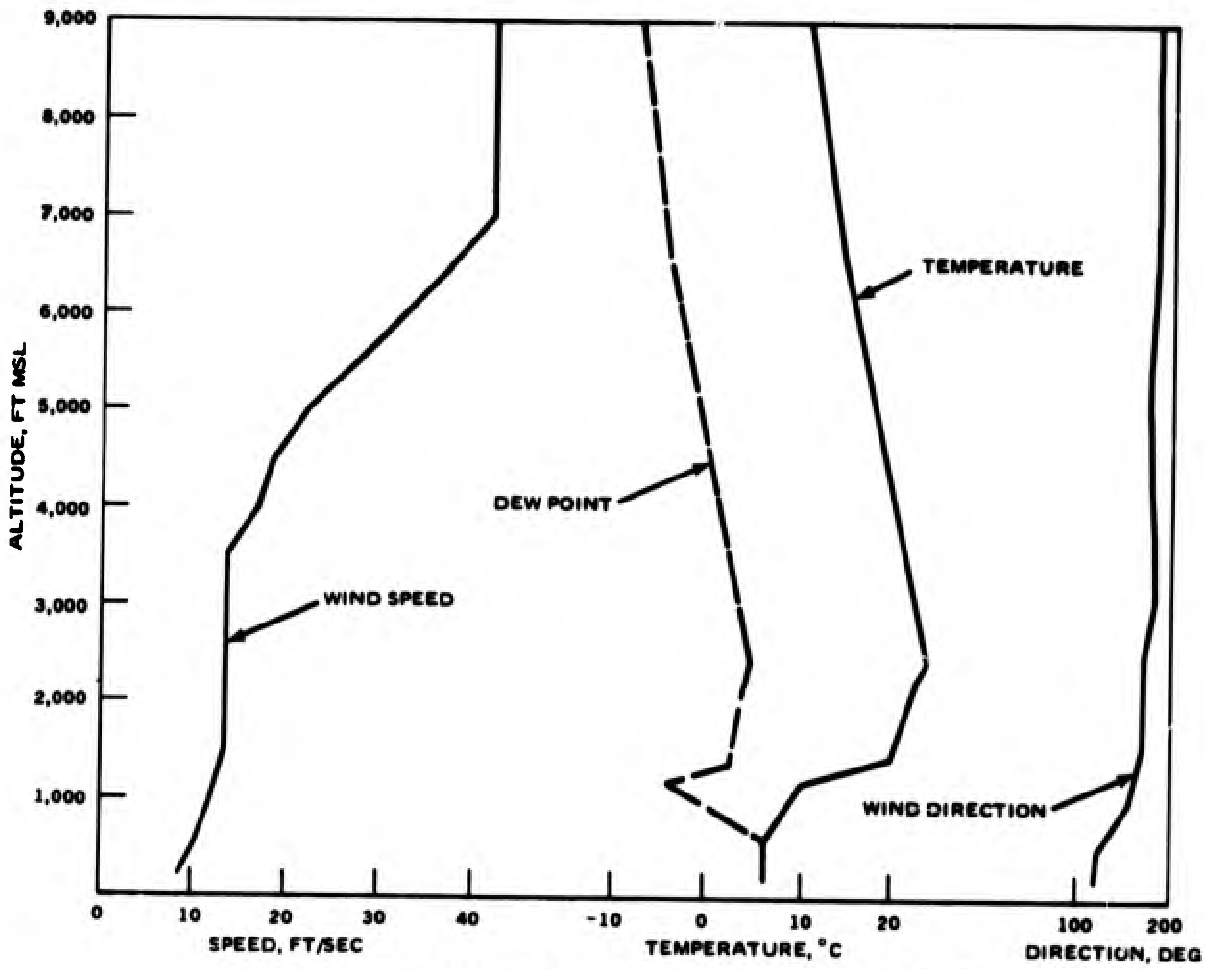


FIG. 41. Test III-15A, Arcata Rawinsonde, 0738 LST, 28 September 1970.

conditions held until midway through the treatment and then began to improve rapidly. Figure 42 reflects these changes. The field was open to flight operations as seeding ended. Maximum clearing was observed 20 minutes after seeding ended with ceiling 200 feet AGL and visibility 1 mile. This clearing was followed by an equally sharp deterioration 30 minutes after seeding ended. The RVR transmissometer gave similar indications with readings going from 1,000 feet to 6,000+ feet during the clearing.

Airborne Observations. Minilab pass data are shown in Fig. 43. As in Test III-15A, all parameters show the desired trends.

Photography. The break-up in the fog was observed and photographed from both the air and the ground. Figure 44 provides a series of views of the fog top and surface conditions taken at approximately identical times.

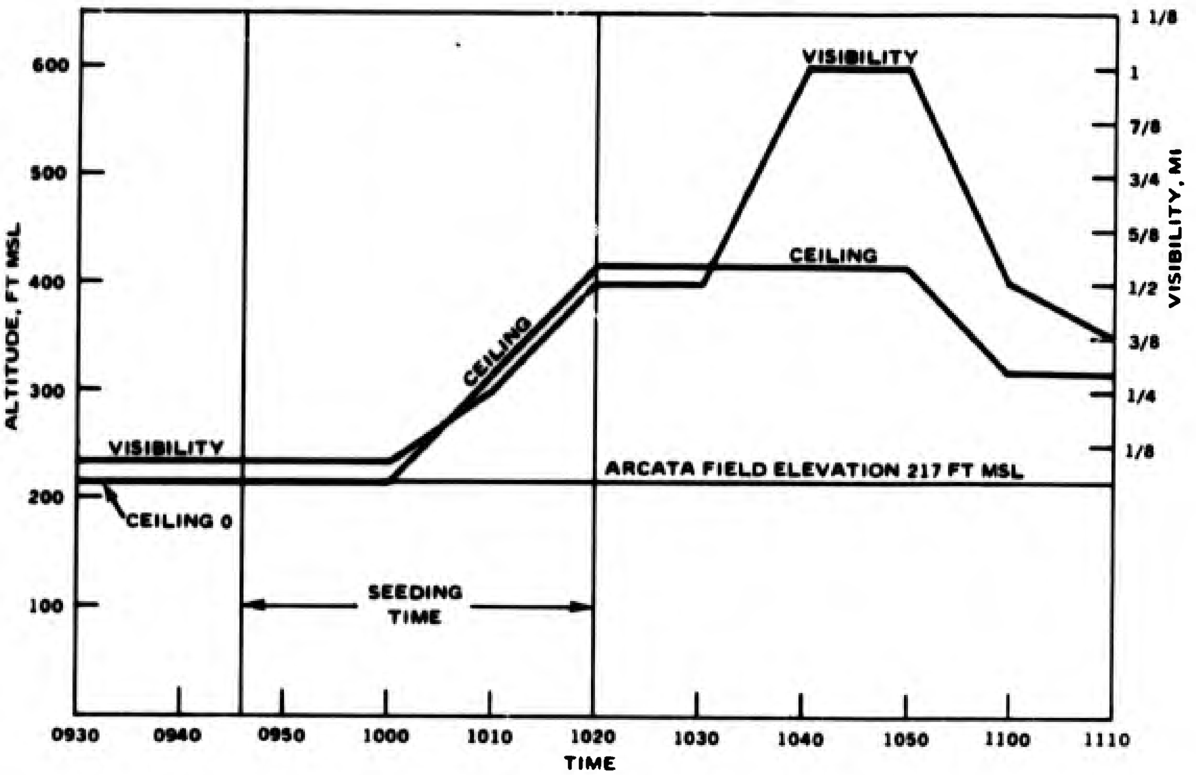


FIG. 42. Test III-15A, Ceiling and Visibility.

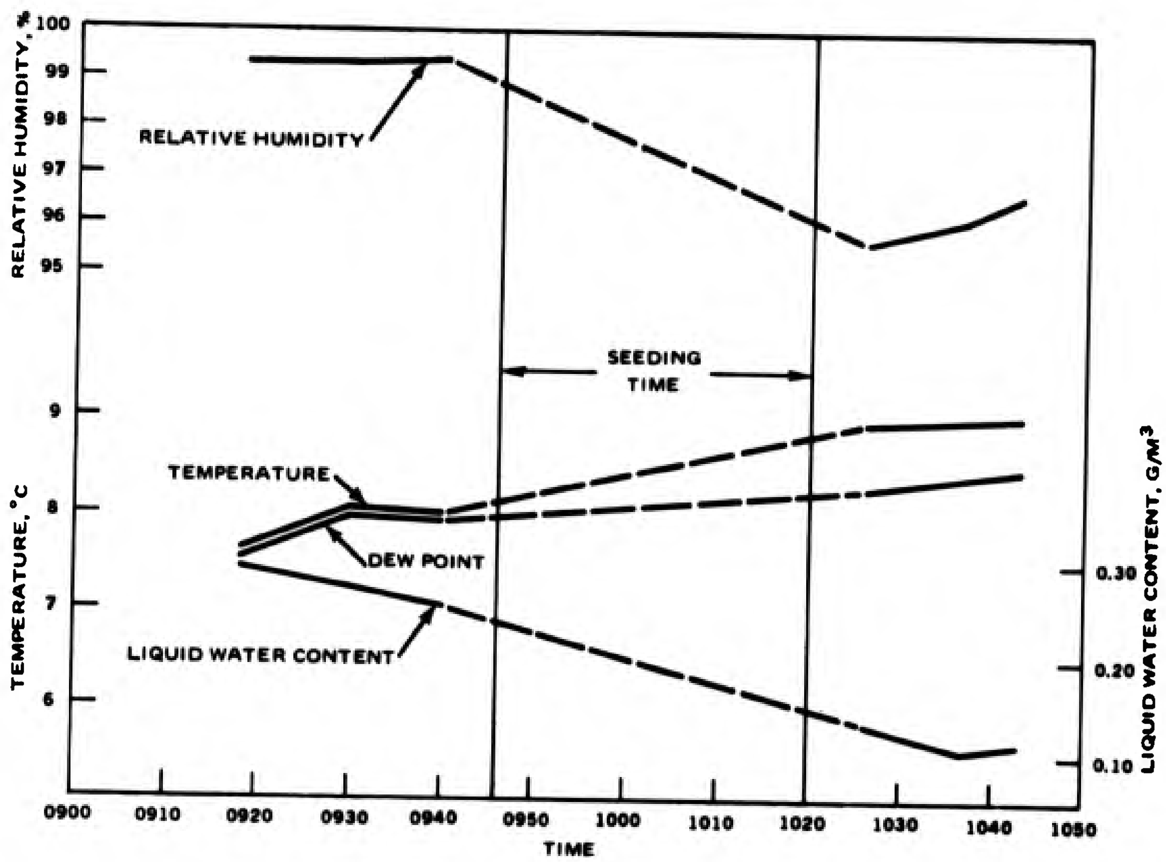
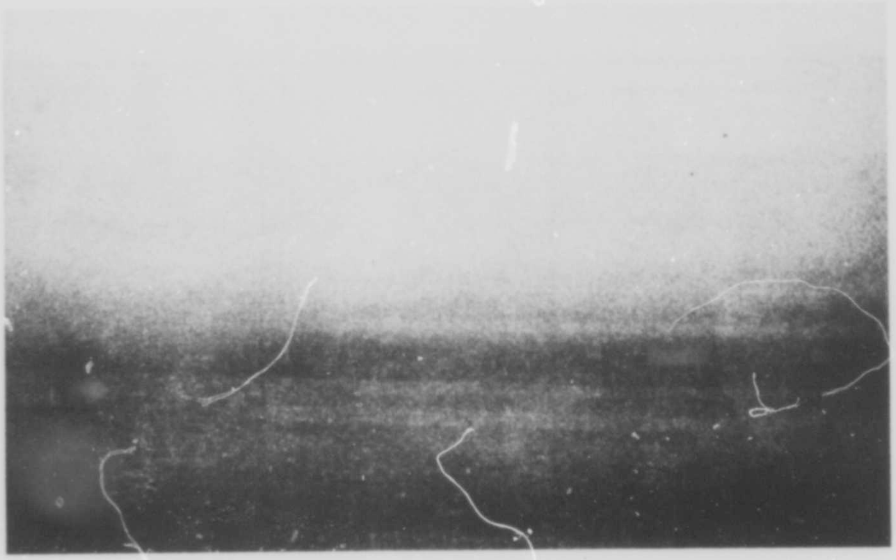
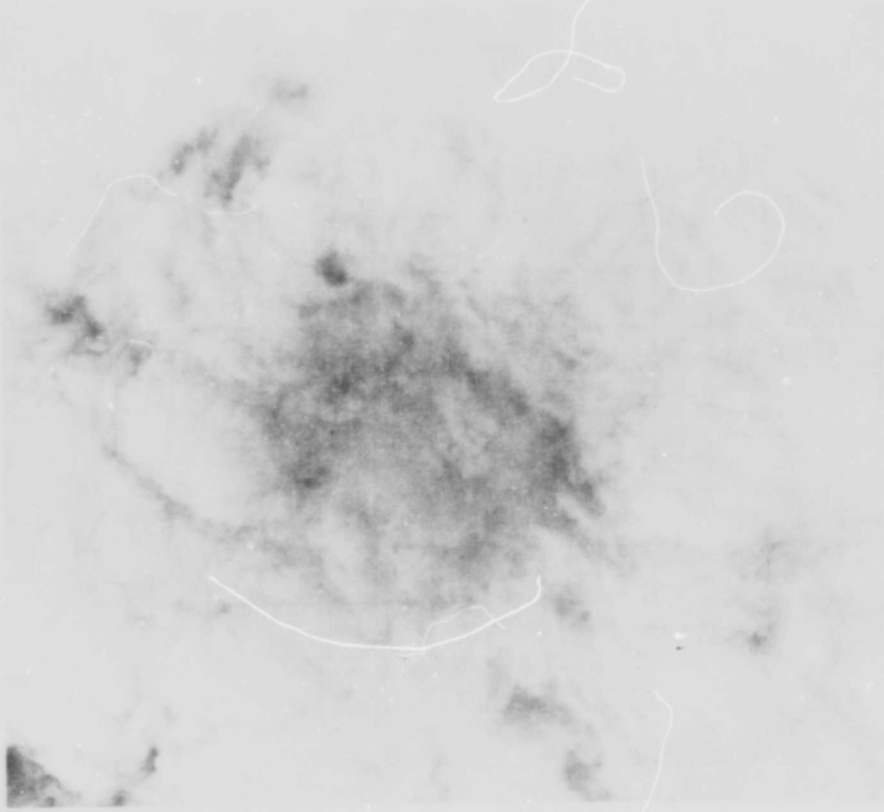


FIG. 43. Test III-15A, Average Pass Values From South End to North End of Runway 31. Pass altitudes were 550 feet MSL ± 40 feet, 150 feet below seeding altitude. Where dashed lines are shown, no data were taken.



(a) Surface conditions 4 minutes after seeding began.



(b) Fog top 3 minutes after seeding began.

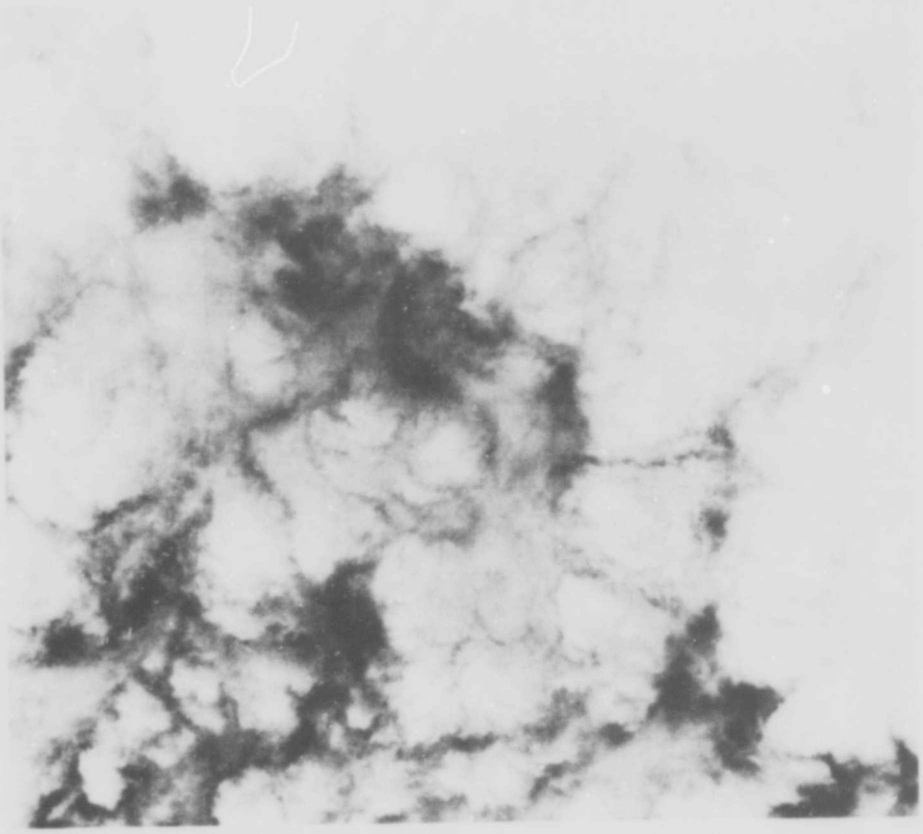
FIG. 44. Test III-15A, Surface and Fog Top Conditions During and After Seeding.

(c) Surface conditions 2 minutes after seeding ended.

(d) Fog top 4 minutes after seeding ended.

FIG. 44 (Contd.)

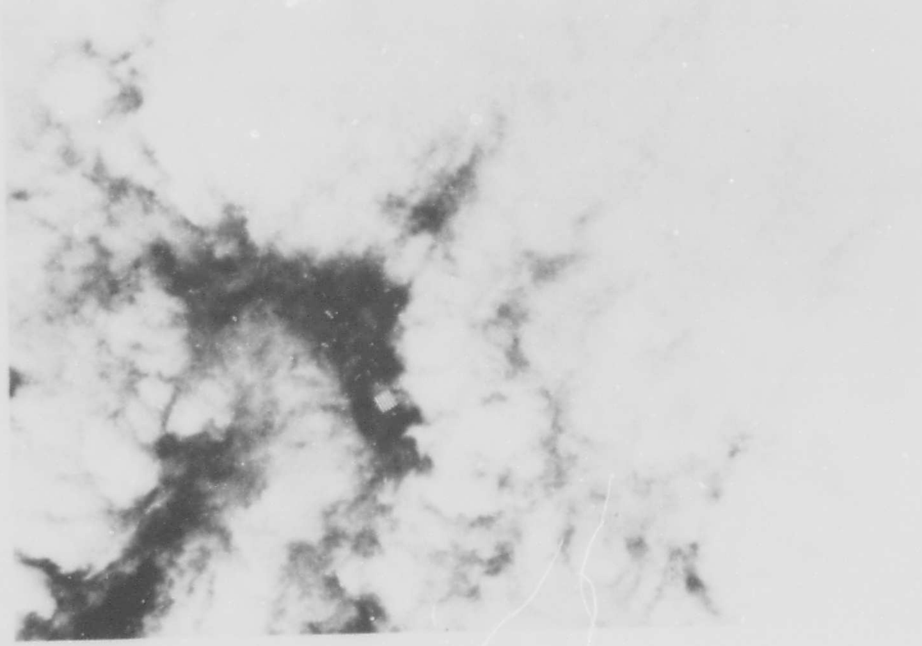
(e) Surface conditions 22 minutes after seeding ended.



(f) Fog top 22 minutes after seeding ended.

FIG. 44 (Contd.)

(g) Surface conditions 33 minutes after seeding ended.



(h) Fog top 27 minutes after seeding ended; note Runway 19 in sight.

FIG. 44 (Contd.)

(i) Surface conditions 44 minutes after seeding ended.

(j) Fog top 52 minutes after seeding ended; field no longer visible.

FIG. 44 (Contd.)

Test III-16A, 2 October

The test design for the seeding aircraft was as follows:

Aircraft B-26
Speed, knots IAS 130
Altitude, ft AGL 750
Flight pattern .... dog-bone

Passes:
No. 11
Duration, sec 27

Solution:
Ratio 9:1
Amount, gal 1,000
Spray rate, gal/min 200
No. of nozzles 86

Time of seeding:
Begin 1011
End 1041

Fog Conditions and Surface Observations. A dense, stable fog had persisted at the airport throughout the night and morning with the field holding below minimums. Fog top was 650 feet AGL. Fixed-wing aircraft seeding was delayed while a Phase II helicopter test was conducted. Figure 45 depicts atmospheric conditions about a half hour before seeding began. There is some question as to its validity, however, as the moisture profile does not indicate fog to 850 feet MSL. A vector wind of 240 degrees at 3.6 knots was used for targeting.

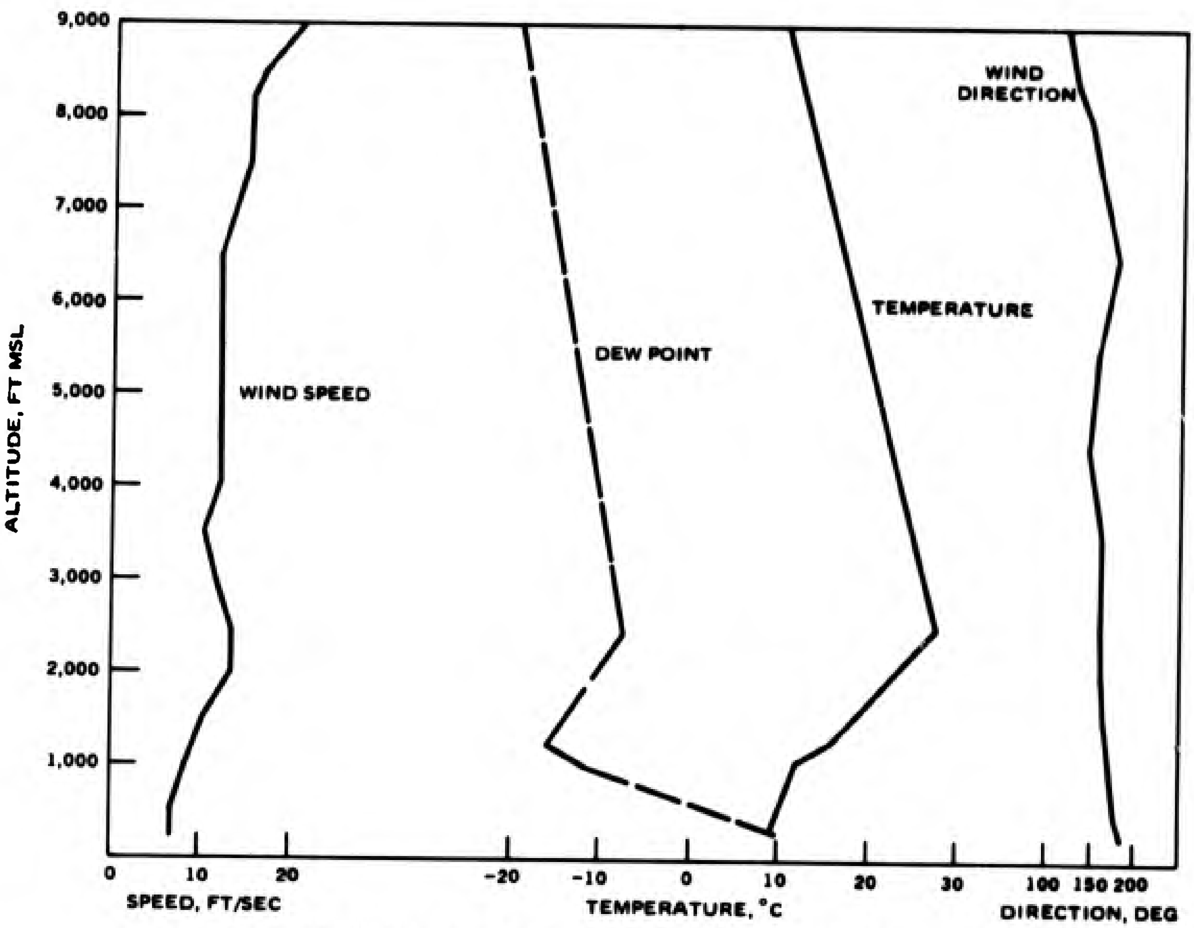


FIG. 45. Test III-16A, Arcata Rawinsonde, 0939 LST, 2 October 1970.

There was little change in field conditions during seeding with ceiling and visibility zero, zero. Nine minutes after seeding ended, improvement began. This improvement peaked-out at ceiling 200 feet AGL, visibility 1/2 mile (field minimums) (Fig. 46). After attaining minimums, the field remained so for about 20 minutes, then worsened for a short while, and finally a natural lifting began. The RVR transmissometer, while somewhat erratic, in general showed the clearing and

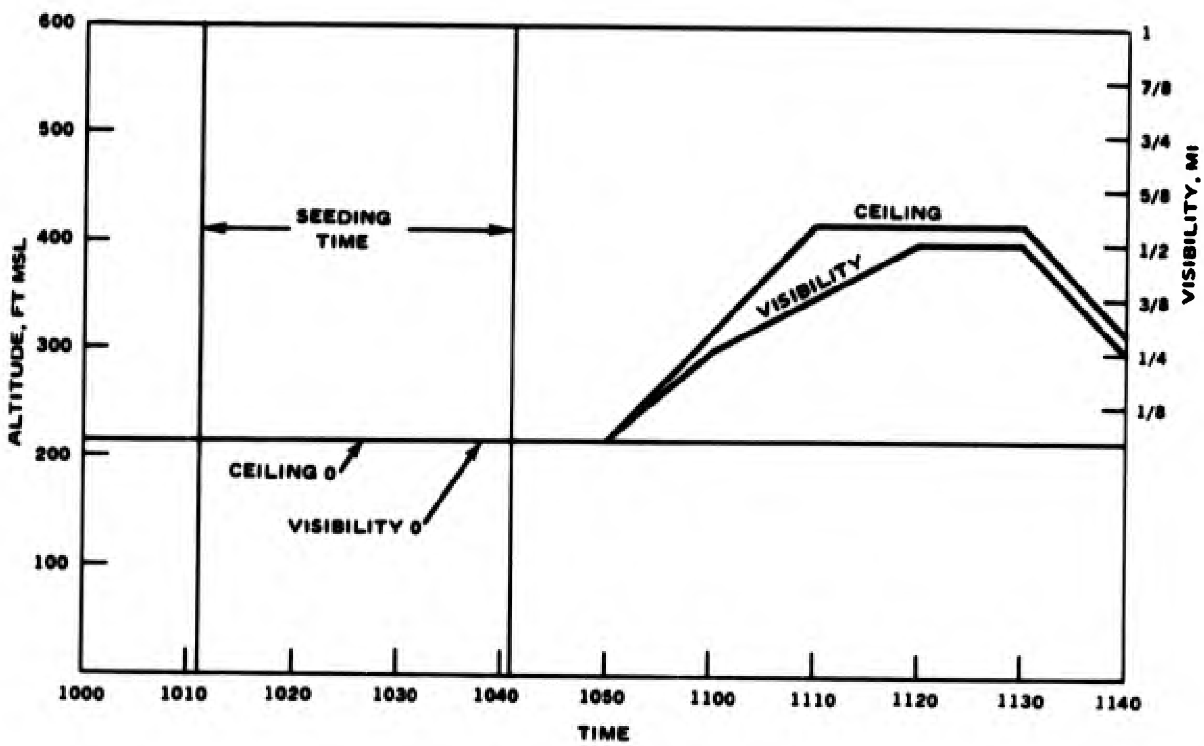


FIG. 46. Test III-16A, Ceiling and Visibility.

deteriorating trends. Droplet count (Fig. 47) showed a decrease following seeding, while median droplet size shifted to a slightly larger value.

Airborne Observations. Average Minilab pass values are shown in Fig. 48. Trend reversals in relative humidity, temperature, liquid water content, and temperature/dew point spread are noted.

Photography. Aerial photography did not provide anything meaningful; however, surface photography (Fig. 49) documented changes in underlying surface conditions.

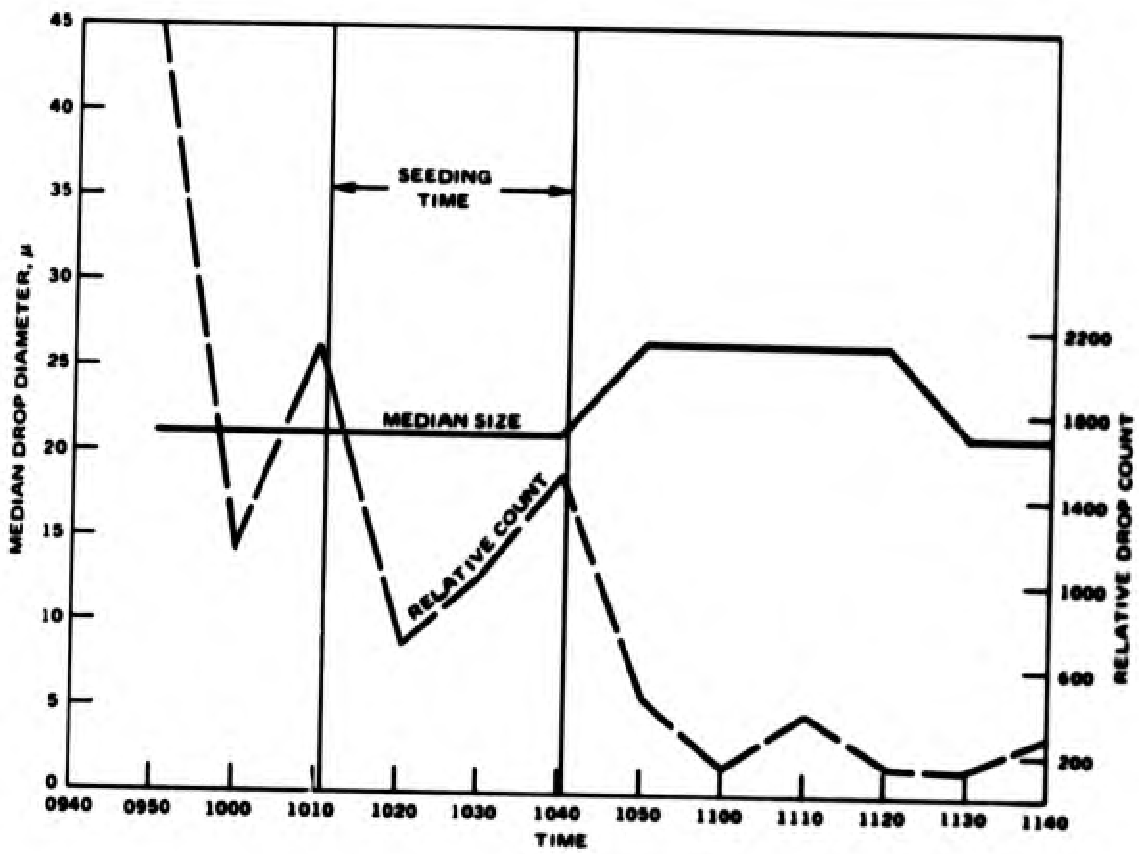


FIG. 47. Test III-16A, Relative Drop Count and Median Size.

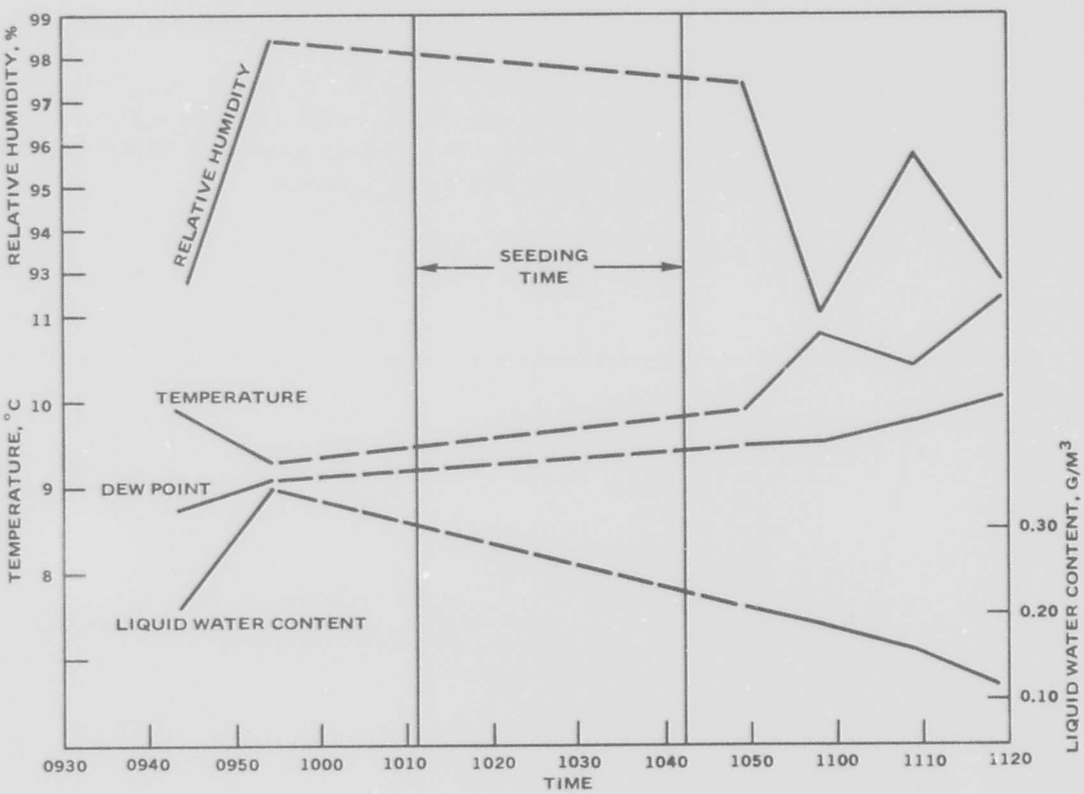
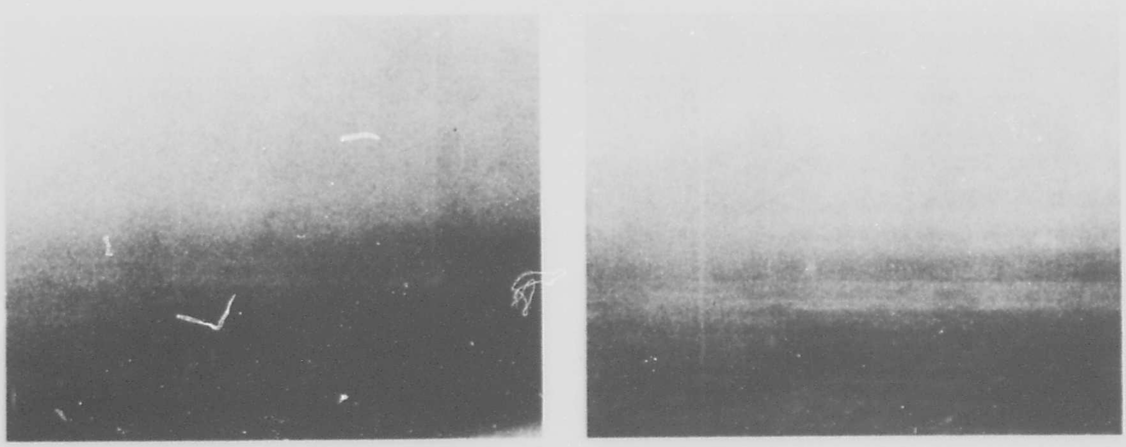


FIG. 48. Test III-16A, Average Pass Values From South to North End of Runway 31. Pass altitudes were 450 feet MSL ± 25 feet, 500 feet below seeding altitude. Where dashed lines are shown, no data were taken.

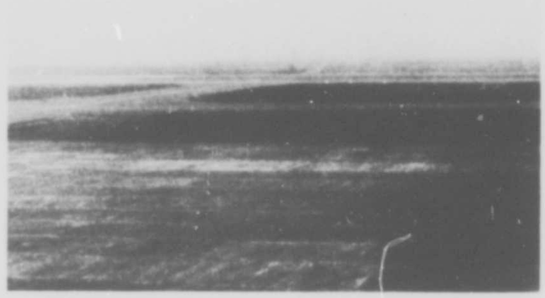


(a) Eleven minutes before seeding began.

(b) One minute before seeding ended.

FIG. 49. Test III-16A, Surface Conditions Before and After Seeding.

(c) Nineteen minutes after seeding ended.



(d) Thirty-nine minutes after seeding ended.

(e) Fifty-nine minutes after seeding ended.

FIG. 49 (Contd.)

SUMMARY OF INDIVIDUAL TESTS

Information concerned primarily with the operational aspects of testing, is contained in Table 6. Individual test cases are summarized below.

Test III-1A

Dense fog had persisted at the airport for 2 hours prior to seeding, with ceiling zero and visibility 1/16 to 1/8 mile. Fog top was 700 feet AGL. Seven minutes after the second seeding pass,

TABLE 6. Summary of Test Seeding Operations.

Date, 1970	Test No.	Air-craft	Solution load		No. of nozzles	Flow rate, gal/min	Pump pres-sure, psi	Fog altitude at initial seeding time, ft AGL		Seeding			Seeding patt
			Type	Amount, gal				Base	Top	Altitude, ft AGL	Time (LST) Begin	End	
27 Jul.	III-1A	B-26	9:1	1,000	86	265	50	0	700	600	0846	0940	Racetrack; five 45-sec legs from end of Runway 31
4 Aug.	III-2A	B-26	14:1	875	86	225	40	300	2,300	1,000	0813	0904	Racetrack; six legs (50, 30, 20, from middle marker to north
7 Aug.	III-3A	B-26	9:1	600	86	167	40	100	400	400	0912	0915	Orbital at sea; 3.6-min continuous
16 Aug.	III-4A	B-26	9:1	1,000	86	285	40	200	1,600	700	0722	0734	Dog-bone; seven 30-sec legs; offset
18 Aug.	III-5A	B-26	9:1	1,000	86	300	40	200	900	700	0942	1005	Dog-bone; eight 25-sec legs; offset
18 Aug.	III-6A	B-26	9:1	1,000	Dump	1,200	40	100	700	800	1234	1235	Dump at sea; 1/4 orbit
20 Aug.	III-7A	B-26	9:1	1,000	86	285	40	300	1,500	800	1056	1139	Dog-bone; three 28-sec legs; offset
25 Aug.	III-8A	B-26	9:1	1,000	76	285	40	100	600	600	0806	0820	Dog-bone; seven 33-sec legs; photography aircrafι
25 Aug.	III-9A	DC-7	9:1	2,000	100	405	80	100	500	500	0943 1042	1002 1052	Dog-bone; two phases; seven 27- legs; offset to Runway 31
28 Aug.	III-10A	DC-7	H_2O	1,000	100	450	80	1,000	1,900	1,500	0906	0943	Dog-bone; six 27-sec legs; offset to
29 Aug.	III-11A	DC-7	H_2O	3,000	100	420	80	200	1,400	1,400	0708 0756 0842	0720 0809 0853	Dog-bone; pulsed; five 28-sec legs
29 Aug.	III-12A	B-26	9:1	1,000	76	245	40	100	1,200	900	1002	1025	Dog-bone; pulsed; nine 27-sec legs
16 Sept.	III-13A	DC-7	9:1	2,000	(a)	280	40	200	1,400	900	0813	0821	Dog-bone; four 28-sec legs for each
23 Sept.	III-14A	B-26	9:1	1,000	86	100	. . .	100	1,800	1,800	1041	1051	Orbital at sea; 10 min continuous
28 Sept.	III-15A	B-26	9:1	1,000	86	230	50	0	750	500	0946	1020	Dog-bone; ten 26-sec legs; offset to
2 Oct.	III-16A	B-26	9:1	1,000	86	200	50	0	650	750	1011	1041	Dog-bone; eleven 27-sec legs; offset
10 Oct.	III-17A	B-26	9:1	1,000	86	220	50	0	1,000	600	0818	0846	Dog-bone; eleven 25-sec legs; offset
14 Oct.	III-18A	B-26	9:1	1,000	86	200	50	800	1,400	1,400[b]	1138	1210	Dog-bone; nine 34-sec legs, each lo Runway 31
15 Oct.	III-19A	B-26	9:1	1,000	86	175	50	200	1,500	800	0825	0910	Dog-bone; eleven 31-sec legs; offset

[a] Twelve nozzles, twelve openings without nozzles, and an open 1-in-diameter tube at each wing tip.
[b] Stepped down from 1,400 ft at 100-ft intervals.

E 6. Summary of Test Seeding Operations.

Seeding			Seeding pattern	Remarks
de, SL	Time (LST)			
	Begin	End		
0	0846	0940	Racetrack; five 45-sec legs from middle marker to north end of Runway 31	Radar down; seeded over airport; field came above minimums after second seeding run
0	0813	0904	Racetrack; six legs (50, 30, 20, 45, 45, and 45 sec) offset from middle marker to north end of Runway 31	Traffic delayed operations; poor test conditions; layered stratus; improvement noted
0	0912	0915	Orbital at sea; 3.6-min continuous spray	Planned test over airport aborted due to fluctuating conditions; broken-up area persisted for 10 min following seeding at sea
0	0722	0734	Dog-bone; seven 30-sec legs; offset to Runway 31	Smooth operations; field had minimums initially, improvement at airport
0	0942	1005	Dog-bone; eight 25-sec legs; offset to Runway 31	Smooth operations; field had minimums initially; clearing pulse followed by deterioration
0	1234	1235	Dump at sea; 1/4 orbit	Planned test aborted; pump malfunction; 200 ft of fog top collapsed
0	1056	1139	Dog-bone; three 28-sec legs; offset to Runway 31	Field well above minimums initially; traffic delay and equipment malfunction; incomplete test
	0806	0820	Dog-bone; seven 33-sec legs; aerial control by pilot of photography aircraft	Radar down; fog intensifying initially; seeded directly over airport; slight clearing pulse
	0943 1042	1002 1052	Dog-bone; two phases; seven 27-sec legs and four 27-sec legs; offset to Runway 31	Initially field was below minimums; 12 min after Phase I, above minimums and held for 24 min; after 4th pass of Phase II, above minimums; traffic precluded completion
	0906	0943	Dog-bone; six 27-sec legs; offset to Runway 31	Rutty high stratus; sharp cuts; traffic aborted Phases II and III
	0708 0756 0842	0720 0809 0853	Dog-bone; pulsed; five 28-sec legs for each of three phases	Deterioration after Phase I; recovery after Phase II that persisted through Phase III
	1002	1025	Dog-bone; pulsed; nine 27-sec legs	Strong clearing pulse followed by deterioration; good timing; field came above minimums
	0813	0821	Dog-bone; four 28-sec legs for each of two phases	Field above minimums entire period; effects, if any, masked in steady natural clearing
	1041	1051	Orbital at sea; 10 min continuous spray	Planned test over airport aborted—equipment and traffic problems; small breaks shortly after seeding; 35 min after seeding, VFR hole opened along projected path
	0946	1020	Dog-bone; ten 26-sec legs; offset to Runway 31	Good effect; airport above minimums in expected time frame
	1011	1041	Dog-bone; eleven 27-sec legs; offset to Runway 31	Good effect; airport above minimums in expected time frame
b	0818	0846	Dog-bone; eleven 25-sec legs; offset to Runway 31	Fog intensifying during seeding; no significant effects noted
	1138	1210	Dog-bone; nine 34-sec legs, each lower by 100 ft; offset to Runway 31	New technique; high stratus; rift developed over field; several holes through to runway
	0825	0910	Dog-bone; eleven 31-sec legs; offset to Runway 31	As in Test III-13A, steady natural clearing, masking any surface effects; a rift through to ground moved across airport 15 min after seeding

conditions improved abruptly to ceiling 200 feet AGL, visibility 1/2 mile, and the airport was above minimums. Seven minutes after the fourth seeding pass, further improvement, to ceiling 300 feet AGL, visibility 3 miles, was noted. Eight minutes after the fifth, and final, seeding pass, visibility had once again lowered to 3/4 mile and remained so for a short period of time, followed by a slow, steady natural clearing.

Droplet count, which showed an increasing trend as seeding began, decreased to zero count following the third seeding pass. LWC values decreased from a preseed maximum of 0.16 g/m^3 and an average of 0.1 g/m^3 to a postseed value of 0.0 g/m^3. Relative humidity decreased from 99 to 95% and temperature increased 1.9°C.

Test III-2A

Field conditions had fluctuated somewhat during the hour before seeding, with fog tending to develop beneath a stratus layer. The airport was above minimums at all times with ceiling 300 feet AGL, visibility 3/4 mile observed at the commencement of seeding. Four seeding passes were made in 23 minutes, after which the operation was held up temporarily due to airport traffic. Nine minutes after the fourth seeding pass, the ceiling was holding at 300 feet AGL; however, visibility had increased to 2 miles. After holding for 22 minutes, seeding was resumed and the final two passes accomplished in 4 minutes. Two minutes after the final pass, conditions had further improved to ceiling 1,000 feet AGL, visibility 3 miles and the airport was under visual flight rules (VFR).

With a ceiling of 300 feet AGL, relatively few drops were recorded and no trend established. Average LWC decreased from a preseed 0.05 g/m^3 to a postseed value of 0.0 g/m^3. Temperature rose 0.3°C and relative humidity dropped 6%.

Test III-3A

Fluctuating conditions at the airport precluded planned over-airport testing, and the operation was moved to sea, where a solid, stable 300-foot-thick fog layer existed (with ceiling 100 feet MSL and top at 400 feet MSL). Seeding was conducted in an orbital pattern with 600 gallons of solution expended in 3.6 minutes. Ten minutes after seeding, the seeded area began breaking up, and the ocean surface was visible through several breaks. The surrounding fog remained solid. Twenty minutes after seeding, the broken area began closing back in with no evidence of seeding noted 25 minutes after seeding ended.

Test III-4A

(See Selected Tests)

Test III-5A

(See Selected Tests)

Test III-6A

Due to a pump malfunction in the B-26 seeder aircraft, this test was carried out as an emergency dump at sea. The fog at sea was 600 feet thick and uniform with ceiling at 100 feet MSL. Dumping the total load of 1,000 gallons of solution took less than a minute and was accomplished while in an orbit. While there was immediate troughing along the dump trail, this effect was short-lived, closing in rapidly. A more significant observation was a collapse of 200 feet in the seeded area fog top.

Test III-7A

Fog conditions were extremely variable for the 4-hour period before seeding and continued to fluctuate, both during and after seeding. Conditions, as seeding began, were ceiling 300 feet AGL, visibility 1-3/4 miles. Higher than normal airport traffic was in progress. Only three seeding passes were accomplished over a period of 45 minutes. Effects of seeding, if any, were masked in natural variations of the stratus. Lengthy delays between seeding passes prohibited meaningful Minilab data passes. Because of poor operational conditions, results from this test must be considered inconclusive.

Test III-8A

Fog conditions were intensifying rapidly as seeding began. Field conditions, which had been above minimums 2 hours before seeding, had worsened to near zero, zero as seeding commenced. A radar malfunction necessitated seeding directly over the airport at fog top that was 600 feet AGL. Seven passes were accomplished in 14 minutes. A single, short-lived clearing pulse occurred 9 minutes after seeding ended, with conditions becoming ceiling 100 feet AGL, visibility 1/8 mile. After a few minutes, conditions deteriorated back to near zero, zero. Conditions thereafter slowly improved with the airport reaching minimums about 1 hour after seeding ended. No other data source indicated positive effects from seeding. This test points out the difficulty of treating fogs in a dynamic growth state.

Test III-9A

This was a two-phase solution test with the DC-7. Field conditions had been below minimums for 3 hours prior to the first phase, with ceiling 100 feet AGL, visibility 3/8 mile as seeding began. Seven passes were completed in 19 minutes. Twelve minutes after seeding ended, the airport was reporting ceiling 200 feet AGL, visibility 1/2 mile, RVR 3,000 feet. Twenty-four minutes later, conditions had worsened again to ceiling 100 feet AGL, visibility 1/4 mile, and the second phase was launched. Upon completion of the fourth pass, the field was once again above minimums and Arcata requested termination of operations to permit normal traffic flow, which was stacked-up. This precluded Minilab data collection following the second phase.

A single preseed and two postseed Minilab passes were made for the first phase. Temperature increased 0.4°C and relative humidity decreased from 99 to 97%. Average LWC decreased 0.03 g/m^3, while droplet count showed trends reflecting decreasing and increasing field conditions.

Test III-10A

This test was designed to measure the effects of seeding a stratus layer with tap water. The layer was based at 1,000 feet AGL with tops 1,900 feet AGL. The DC-7 was loaded with 3,000 gallons, and it was planned to repeat the test three times using 1,000 gallons per test. The airport was VFR at all times. The stratus layer appeared dissipative and maximum LWC measured was 0.03 g/m^3. Immediately following the third DC-7 pass, a trough developed through the entire layer. The trough was about 1/4 mile wide and the airport was visible through it. Three additional passes were made and the trough persisted. The second and third phases were canceled due to heavy airport traffic and near complete disintegration of the stratus layer over the airport.

Test III-11A

This test consisted of three phases. The DC-7 was loaded with 3,000 gallons of water and dispensed 1,000 gallons per phase. Each phase was separated in time by about 30 minutes. Ceiling and visibility, as Phase I began, were 200 feet AGL and 1/2 mile with the airport holding bare minimums. No appreciable change was noted until 25 minutes after Phase I was complete, at which time conditions lowered to ceiling 100 feet AGL, visibility 1/8 to 1/4 mile. These conditions held as Phase II began. Eight minutes after completion of Phase II, field conditions improved to ceiling 200 feet AGL, visibility 1/2 mile. This condition continued through Phase III. The official transmissometer (RVR) revealed slight but definite peaks in transmissivity at 11, 8, and 16 minutes after water-seeding ended in the three phases, respectively. Airborne laboratory observations were not definitive, but showed slight variations in temperature and relative humidity. LWC values remained fairly constant at ~0.1 g/m^3 at 400 feet and ~0.2 g/m^3 at 1,000 feet. Droplet analysis shows two density maxima, one occurring between 20 and 30 minutes after Phase I and the other 8 minutes after Phase III began.

Test III-12A

(See Selected Tests)

Test III-13A

The DC-7 was modified so that 1-inch-diameter tubing extended from the spray boom to the wing tips. The six outboard nozzles on each side were removed and the fittings left open; the six inboard nozzles on each side were left in place. The remainder of the nozzle fittings were plugged. These modifications were made to determine the effects of ejecting the solution more directly into the wing-tip vortices. The test was conducted in two phases of 1,000 gallons of 9:1 solution per phase.

Test conditions were poor with the airport well above minimums at all times. As Phase I began, conditions were ceiling 200 feet AGL, visibility 2 miles. Conditions remained unchanged until 27 minutes after Phase I, at which time improvement to ceiling 300 feet AGL, visibility 2-1/2 miles was noted. A gradual, steady clearing occurred thereafter, masking any further effects attributable to seeding. All other data sources reflected this natural clearing.

Test III-14A

The airport was above minimums at all times. After delaying the planned over-airport test for 2 hours due to high airport traffic, it was decided to conduct an on-top orbital solution seeding at sea (ceiling at 100 feet, top at 1,800 feet). With a northwesterly wind flow, seeding was accomplished about 3 miles northwest of the airport just off shore in the vicinity of Moonstone Beach (Fig. 3), in an attempt to project the seeded area over the airport for better data acquisition. Although solution drops were detected at the airport, the major portion of the seeded area drifted south, paralleling the coast. Surface observers reported considerable solution droplet fallout along Clam Beach with a definite increase in light and visibility. Thirty minutes after seeding, a nonproject aircraft reported a large hole about 7 miles south of the airport along the beach. This hole coincides, reasonably, with the projected downwind drift of the seeded area. There were no other breaks in the area. The pilot of the reporting aircraft canceled his instrument flight rules (IFR) flight plan and descended VFR through the break.

Test III-15A

(See Selected Tests)

Test III-16A

(See Selected Tests)

Test III-17A

This was an over-airport solution test using the B-26 in a dog-bone pattern, offset to target Runway 31. Twenty minutes prior to seeding, the airport was reporting ceiling 200 feet AGL, visibility 1/2 mile. Rapid intensification occurred thereafter with conditions becoming ceiling zero, visibility 1/8 mile as seeding began. Field conditions remained unchanged during seeding and after seeding. The droplet analysis showed a slight shift in size distribution to larger drops and a considerable reduction in count 20 minutes after seeding. Twenty minutes later, droplet count and size distribution had returned to their original state. Transmissivity showed no appreciable change. Airborne laboratory data showed no significant change in temperature, relative humidity remained constant at 100%, and LWC showed a steady increase. The results of this test were similar, in many respects, to III-8A.

Test III-18A

After completion of an early morning CH-54 helicopter (Phase II) test, a stratus layer, based at 800 feet AGL with top at 1,400 feet AGL, remained over the airport. An offset dog-bone seeding pattern targeting Runway 31 was employed with the B-26 spraying 1,000 gallons of 9:1 solution. An innovation was seeding on top of the stratus layer on the first pass, then stepping down 100 feet in altitude on each successive pass while the seeded area approached the airport. Once again, airport traffic prohibited an adequate number of Minilab data passes. Twenty minutes after seeding ended, a large rift developed over and parallel to Runway 31. The runway was visible and a VFR descent could easily have been made. The rift moved slowly off to the east. This observation was documented by both surface and airborne observers.

Test III-19A

The initial test plan was to repeat III-18A; however, when the ceiling lowered to 200 feet AGL, the plan was altered to in-cloud seeding 500 feet above base.

Reported field conditions at the onset of seeding were ceiling 200 feet AGL, visibility 3/4 mile. Eleven minutes after the end of seeding, conditions had improved to ceiling 300 feet AGL, visibility 1-1/2 miles. As in Test III-18A, a significant rift in the fog layer developed and moved across the airport. The surface was visible through several spots in the rift. Minilab data passes, which reflected a drying of the layer, were made too infrequently for a meaningful history. Few droplets were collected during the test period, indicating the dryness of the fog; however, of those collected, over 90% were greater than 30 μ in diameter.

While this test is indicative of some success, with special significance attached to the rift development, some question exists regarding ceiling and visibility improvement. Conditions were in a state of flux as seeding began and the improvement trends noted during the course of testing continued unabated after test completion, indicating natural processes were contributing to the observed clearing.

TEST EVALUATION UNDER STEADY-STATE FOG CONDITIONS

Emphasis during Project Foggy Cloud III, Phase I was directed toward improving conditions at a fog-bound airport by applying in-cloud, repeated treatments of 9:1 solution to an approaching fog volume. To facilitate the evaluation of the degree to which this goal was achieved, the analysis was restricted to tests meeting certain criteria. Tests excluded from this analysis were conducted (1) under fluctuating or naturally clearing conditions (III-2A, 7A, 13A, and 19A), (2) on rapidly intensifying fog (III-8A and 17A), (3) over water (III-3A, 6A, and 14A), (4) with water (III-11A), and (5) on high stratus (III-10A and 18A). Tests included were under relatively stable fog conditions and seeding was with 9:1 solution over or upwind of the airport. Seven tests fell within that definition and are summarized in Table 7. From the information shown, certain conclusions may be drawn.

TABLE 7. Effects of Seeding Stable Fog With 9:1 Solution.

Test no.	Conditions at beginning of seeding		Surface observations		Airborne observations		
	Ceiling, ft AGL	Visibility, mi	Ceiling increase, ft AGL	Visibility increase, mi	Temperature increase, °C	Relative humidity decrease, %	Av. LWC decrease, g/m^3
III-1A	0	1/8	300	2-7/8	1.9	4	0.1 (to 0.0)[a]
III-4A	200	1/2	100	1/2	0.0[a]	0[a]	0.12
III-5A	200	3/4	300	1-1/4	1.0	2	0.11
III-9A	100	3/8	200	9/16	0.4	2	0.03
III-12A	100	3/8	200	5/8	NA	NA	NA
III-15A	0	1/16	200	15/16	1.0	4	0.15
III-16A	0	0	200	1/2	1.5	5	0.20
Average	86	5/16	214	1-1/16	1.16	3.4	0.122

[a] Unrealistic values not included in average.

CONCLUSIONS AND RECOMMENDATIONS

Conclusions herein are based on project testing at Arcata, Calif. and do not necessarily imply that similar results can be achieved elsewhere. Before any such extension is attempted, consideration must be given to certain local variations such as fog formative processes, microphysical properties, and atmospheric contamination.

CONCLUSIONS

1. As evidenced in seven out of seven cases, seeding a relatively stable fog with 9:1 solution can effectively improve ceilings and visibilities. The average improvement noted was an increase of 214 feet in ceiling and 1-1/16 miles in visibility.

2. Average in-cloud, but below seeding altitude, parameter changes noted in conjunction with the clearings were an increase in temperature of 1.16°C, a decrease of 3.4% relative humidity, and a decrease of 0.122 g/m^3 in liquid water content.

3. Observations indicate that applying the same treatment to a decaying fog will hasten its dissipation rate.

4. Applying the same treatment to a rapidly intensifying fog may well be for naught. Seeding effects may well be masked, and, if noted at all, may be insignificant.

5. Applying the same treatment to a stable fog, but using tap water instead of solution, can produce measurable effects, but of considerably less significance.

6. Evidence, from the 3-year series of tests, indicates that holes can be effected completely through fogs as thick as 500 feet. Tests conducted on top of thicker fogs have, at times, produced holes; however, results are inconsistent.

RECOMMENDATIONS

1. Studies in progress regarding fog formative processes and cycling and behavior patterns should be continued. Such studies should be directed toward developing techniques to predict the optimum (earliest) time in a fog's life cycle that it is amenable to treatment.

2. A series of experiments should be conducted during Foggy Cloud IV with a nephelometer to provide data of the effects on in-cloud droplet spectra of aircraft wake (vortices), water, and solution.

3. Current plans to optimize the fog dispersal system with the addition of electrostatically charged particles should proceed as rapidly as possible.

Appendix A

CATALOG OF DATA COLLECTED

TABLE 8. Source and Numbered Data Collected During Seeding Tests

Date Test No.	27 Jul. III-1A	4 Aug. III-2A	7 Aug. III-3A	16 Aug. III-4A	18 Aug. III-5A	18 Aug. III-6A	20 Aug. III-7A	25 Aug. III-8A	25 Aug. III-9A	28 Aug. III-10A	29 Aug. III-11A
Tower Data:											
1. Ground station log	1	1	...	1	1	...	1	1	1	1	1
2. Surface weather observer's log	1	1	...	1	1	...	1	1	1	1	1
3. Observer's log	2	1	...	2	2	...	1	2	2	1	3
4. 35-mm slides	1	1	...	1	1	...	1	1	1	1	1
5. Urea paper	1	1	...	1	1	...	1	1	1	...	...
6. Ceilometer chart	1	1	...	1	1	...	1	1	1	1	1
7. Transmissometer record	2	2	...	2	2	...	2	2	2	2	2
8. WBAN (Weather Bureau, Army-Navy), form, surface observer	1	1	1	1	1	1	1	1	1	1	1
9. Droplet slides	1	1	...	1	1	...	...	1	1	1	1
Radar Data:											
1. Seeder aircraft plot	...	1	1	1	1	1	1	...	2	1	3[b]
2. Observer's log	...	...	1	1	1	...	...	1	1	1	2
Rawinsonde Data:											
1. Tabulation	1	2	1	3	2	1	2	2	2	1	2
2. Wind vector	1	2	1	3	1	1	2	1	2	...	4
3. Arowagram	2	1	1	1	2	...	1	1	1	...	1
Seeder Aircraft:											
1. Seeding log	1	1	1	1	1	1	1	1	1	1	1
Minilab Aircraft:											
1. Computer print-out	1	1	1	1	1	1	...	1[c]	1[c]	1[c]	1
2. Computer plot	1	1	1	1	1	1	...	1	1	1	1
3. Oscillograph record	1	1	1	1	1	1	1	1	1	1	1
4. Minilab observer's log	1	1	1	1	1	1	...	1	1	1	1
5. Observer's log	1	1	2	2	2	1	1	2	2	2	1
Control Aircraft:											
1. Observer's log	...	1	2[d]	...	...	...	...	1	1	1	...
Photography Aircraft:											
1. T-11 photos	1	1	1	1	1	1	1	1	1	...	1
2. Observer's log	1	1	1	1	1	1	1	1	1	2	1
Operations briefing notes	1	1	1	1	1	...	1	1	1	...	1
Operations debriefing notes	1	1	1	1	1	...	...	1	1	...	1

[a] Additional observer's log from CB area near Runway 10.
[b] Movies (16-mm) filmed from the radar sight.
[c] Movies (16-mm) filmed from the Minilab.
[d] Movies (16-mm) filmed from the control aircraft.
[e] Additional 35-mm slides from the control aircraft.

Appendix A

CATALOG OF DATA COLLECTED

Source and Numbered Data Collected During Seeding Tests.

Aug. I-5A	18 Aug. III-6A	20 Aug. III-7A	25 Aug. III-8A	25 Aug. III-9A	28 Aug. III-10A	29 Aug. III-11A	29 Aug. III-12A	16 Sept. III-13A	23 Sept. III-14A	28 Sept. III-15A	2 Oct. III-16A	10 Oct. III-17A	14 Oct. III-18A	15 Oct. III-19A
1	...	1	1	1	1	1	1	1	1	1	1	1	1	1
1	...	1	1	1	1	1	1	1	1	1	1	i	1	1
2	...	1	2	2	1	3	3	2	2[a]	1	1	2[a]	1	3
1	...	1	1	1	1	1	1	1	1	1	1	1	1	1
1	...	1	1	1	...	...	1	1	1	...	...	1	...	...
1	...	1	1	1	1	1	1	1	1	1	1	1	1	1
2	...	2	2	2	2	2	2	2	2	2	2	2	2	2
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
1	...	...	1	1	1	1	1	1	1	1	1	1	1	1
1	1	1	...	2	1	3[b]	1[b]	2[b]	1	1	1	1	1	1
1	...	...	1	1	1	2	2	2	2	1	1	2	2	1
2	1	2	2	2	1	2	1	3	2	1	2	1	2	3
1	1	2	1	2	...	4	1	5	3	2	2	1	2	4
2	...	1	1	1	...	1	1	1	1	1	1	1	1	2
1	1	1	1	1	1	1	1	2	1	1	1	1	1	1
1	1	...	1[c]	1[c]	1[c]	1	1	1	1	1	1	1	1	1
1	1	...	1	1	1	1	1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
1	1	...	1	1	1	1	1	1	1	1	1	1	1	1
2	1	1	2	2	2	1	1	1	2	1	...	2	1	2
...	...	...	1	1	1	...	...	...	...	2[c]	1	2	...	...
1	1	1	1	1	...	1	...	1	...	1	1	...	1	1
1	1	1	1	1	2	1	...	1	...	1	1	...	1	1
1	...	1	1	1	...	1	1	1	1	...	1	1	1	1
1	...	...	1	1	...	1	1	1	1	1	1	1	1	1

Appendix B

SUPPORT TEST SUMMARY

TABLE 9. Support Test Summary.

Test no.	Date: 1970	Data acquired
III-E1A	15 Jul.	Surface data collection on untreated fog
III-E2A	16 Jul.	Same as E-1A
III-E3A	17 Jul.	Same as E-1A, plus rawinsonde
III-E4A	18 Jul.	Same as E-1A
III-E5A	20 Jul.	Complete (surface and airborne) data collection on untreated fog
III-E6A	21 Jul.	Same as E-3A
III-E7A	24 Jul.	Same as E-5A
III-E8A	27 Jul.	Planned fog dispersal test aborted; same as E-5A
III-E9A	6 Aug.	Same as E-5A
III-E10A	7 Aug.	Same as E-5A
III-E11A	12 Aug.	Same as E-5A
III-E12A	13 Aug.	Same as E-5A
III-E13A	18 Aug.	Same as E-5A
III-E14A	19 Aug.	DC-7; spray swath test
III-E15A	20 Aug.	Same as E-8A
III-E16A	20 Aug.	Same as E-8A
III-E-17A	27 Aug.	Same as E-14A
III-E18A	15 Sept.	DC-7; dye spray swath; photographic documentation
III-E-19A	15 Sept.	Same as E-18A

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