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WARM FOG DISPERSAL TESTS WITH GLYCERINE AT GREENBRIER VALLEY AIRPORT LEWISBURG, WEST VIRGINIA

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December, 1973
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PHASE II

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16. Abstract

Field tests designed to measure the effectiveness of glycerine as a warm fog dispersal agent were conducted at the Greenbrier Valley Airport, Lewisburg, West Virginia, during the month of September, 1973. The tests were designed to provide a quantitative relationship between the amount of glycerine used and the resultant improvement in visibility. Problem areas such as controlled particulation, improved analytical evaluation, and more accurate targeting capability were emphasized.

The test results verified that isolated areas of improved visibility were produced by the seeding experiments. However, the test results also indicate that the effects produced by shear winds will be an overriding factor in determining the quantity of glycerine required to open a "fogged in" airport.

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PREFACE

The work reported in this document was conducted at the Greenbrier Valley Airport, near Lewisburg, West Virginia, during the month of September, 1973. It is a follow-on of the work done in conjunction with Foggy Cloud IV conducted at Arcata, California in 1971 and Foggy Cloud V conducted in the Panama Canal Zone during the latter part of 1972. It was concluded from project Foggy Cloud IV and later verified from Foggy Cloud V that glycerine was an effective fog dispersal agent. However, due to limitations in both experiments, the quantity of seeding agent required to open a "fogged in" airport could not be determined. A highly instrumented experiment with prime emphasis on measurement was developed for use in a third attempt to evaluate the effectiveness of glycerine.

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INTRODUCTION

It has been adequately demonstrated that properly particulated glycerine could significantly alter the dissipation rate of warm fog (1, 2). A combination of several physical properties is thought to contribute to the mechanism(s) of response. Glycerine has a very high affinity for water which upon exposure to the atmosphere can reduce the atmospheric moisture vapor concentration. A selective reduction in the vapor concentration will be accompanied by a liquid to vapor transition to reestablish equilibrium--the fog serving as the source of the depleted liquid. Glycerine exerts a very low vapor pressure (compared to water) which could enhance the coalescence efficiency with fog particles thus lending weight to the orthokinetic or "sweep-out" theory. Other factors such as a high migration constant for water in glycerine (thus allowing rapid solution equilibrium following droplet collision and coalescence) may also contribute to its effectiveness as an agent for dissipating fog.

The aforereferenced experiments were not designed to provide quantitative information related to effectiveness, therefore the results could not be equated to the ultimate objective of opening up a "fogged in" airport. The objective of the experimental work covered by this report was to measure the effectiveness of glycerine as an agent for dissipating naturally occurring warm fog.

To achieve the stated objective, several new problem areas such as controlled particulation, more accurate targeting capability, and improved analytical evaluation had to be solved. With the knowledge and experience gained from the previous field tests a new experimental plan was devised to evaluate the effectiveness of glycerine. Arrangements were made through F. A. A. sponsorship to conduct the proposed experimental plan at the Greenbrier Valley Airport, Lewisburg, West Virginia, during the month of September, 1973.

The Greenbrier Valley area was chosen as the test site for the glycerine experiments primarily because climatological data (3) indicated that the central Appalachian regions are the ones most subject to radiation-type fogs. August is usually the period of highest fog frequency; however, due to problems in scheduling, the Dow experiments were not conducted until the month of September. The referenced climatology records include only the fog frequency and surface wind data. The fog incident data used to compile frequency was

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[1] McDuff, J. M., "Test of Polyhydric Chemicals for Fog Dispersal," FAA Report No. FAA-RD-72-13.

[2] McDuff, J. M., et. al., "Warm Fog Dispersal Tests With Glycerine in the Panama Canal Zone," FAA Report No. FAA-RD-73-21.

[3] "Climatology of Appalachian Valley Fog at White Sulfur Springs, West Virginia and Near-by Stations During Months of Peak Fog Frequency," Alfred A. Spatola, AFCRL-72-0054.

based on observer reports while the wind speed and direction were obtained only at ground level using conventional wind instruments. A more detailed study of the prevailing atmospheric conditions at the Greenbrier Valley Airport during the month of September produced several departures from the expected. Two transmissometers were operational continuously September 6 through October 1, and during that period twelve fogs occurred at the test site. Based on visual evaluations, each fog would have contributed to the statistical fog frequency ($\leq$0.25 mile surface visibility). Although five tests were attempted, the transmissometer records revealed that only three fogs (September 16, 24, and 28) were of sufficient duration and stability to permit meaningful testing.

EXPERIMENTAL PROCEDURE

Liquid glycerine was particulated and uniformly dispersed over a specified area at the top of a fog. The release (seeding) area with respect to the primary target area was determined by the average wind direction and speed between ground level and the fog tops. The wind conditions were monitored and the resultant seeding azimuth and up-wind distance were continuously updated throughout the experimental period. The seeding release area was identified by tethered marker balloons. The seeding vehicle (helicopter) assumed a position relative to the marker balloons and began flying a seeding pattern. Following ground confirmation of its location, the helicopter flew a normal seeding pattern to establish any potential vehicle downwash effect on ground instrument response. Upon command, the spray system was activated and glycerine was discharged at a controlled rate until the seeding load had been depleted. The helicopter was then directed to assume a position above and in line with the affected area where the pilot made visual observations and photographs of the results, as safety of flight permitted. Following the completed test, the helicopter returned to its staging area on an adjacent mountain and prepared for the next test.

DESCRIPTION OF EQUIPMENT AND APPARATUS

1. Seeding System

   a. Delivery Vehicle. The delivery vehicle used throughout the experimental period was a Model 206-B Bell Jet Ranger-II helicopter (Figure 1a). The net payload capability (after weight adjustments for fuel, pilot, equipment, etc.) was 800 pounds. The helicopter was capable of providing auxillary electrical power at a rate of 2.6 horsepower (80 amperes @ 24 volts).

   b. Helicopter Landing Site. The helicopter was based on top of Muddy Creek Mountain at an altitude of 2900 feet MSL (Figure 2) or about 650 feet above the runway elevation. The site was located on a 235° azimuth, 8.5 miles from the target area. The peak of Weaver's Knob at an elevation of 2920 feet MSL was located about 3.2 miles from the

Figure 1a. Helicopter at staging area on top of Muddy Creek Mountain.

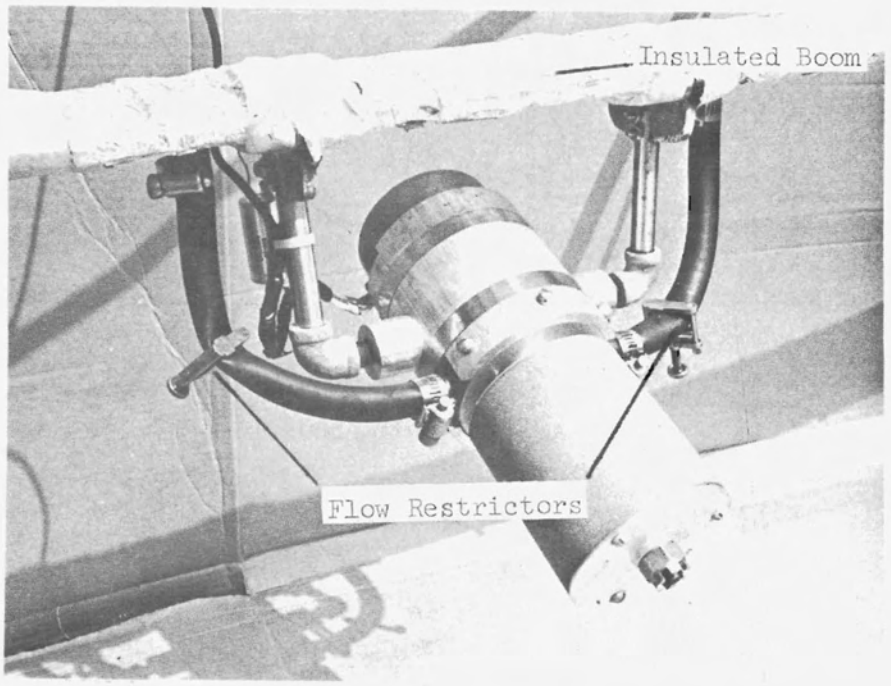

Figure 1b. Rotary mechanical particulator mounted on airfoil boom. Note pinch-clamps hose restriction used to adjust liquid flow to particulator.

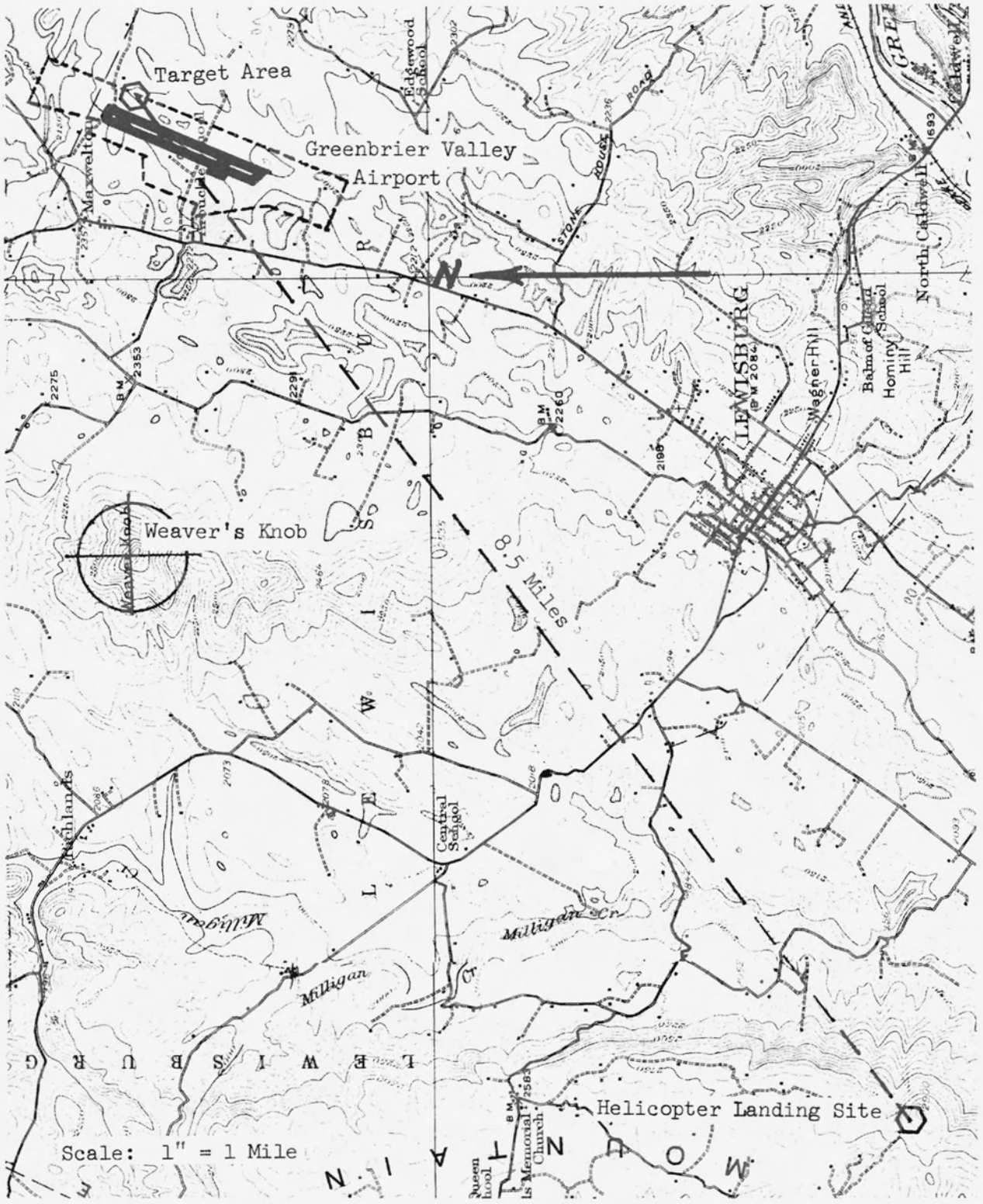

Figure 2. Map of Test Zone.

target area on a 268° azimuth and served as a visual reference point during flight operations.

c. Particulators. Liquid break-up was accomplished through the use of six Beecomist Model 375 rotary mechanical particulators (Figure 1b). The particulator uses a porous metal sleeve rotated at a high speed by a 1/4 h.p. electric motor. The glycerine is metered to the inside of the rotating sleeve and by centrifugal force is expelled through the sleeve and into the surrounding atmosphere where air shear reduces the liquid to tiny droplets (20 - 80 micrometer diameter). The rotating sleeve is composed of fused, uniformly sized metal (316 stainless steel) spheres. The effective sleeve orifice consists of the many channels generated by the voids separating the microspheres.

Particulator Specifications:

Rotating Sleeve Diameter	3.5 inches
Rotating Sleeve Length	4.0 inches
Rotating Sleeve Porosity (orifice diameter)	40 micrometers
Rotating Sleeve Peripheral Velocity @ 10,000 rpm	153 ft. $sec.^{-1}$
Motor Rated Work Capacity	0.3 horsepower
Total Weight	8.0 pounds

d. Liquid System. Glycerine was stored in 55-gallon drums at the staging area on top of Muddy Creek Mountain (Figure 3a). Glycerine was transferred from the drums to the helicopter by means of an electrically driven gear pump (Figure 3b). Two full drums were equipped with electrical immersion heaters which maintained the contents above or near 50°C. A specially designed (Omniflight Helicopters, Inc.) fiber glass reinforced polyester tank was attached to the bottom of the helicopter. The tank was equipped with thermostatically controlled electrical immersion heaters that maintained the glycerine temperature at approximately 55°C.

During a test, the heated glycerine was pumped from the helicopter tank to the particulators by means of an electrically driven positive displacement pump (Figure 4a). The pump drive motor speed was electronically controlled, regulated, and monitored (via telemetry) in real time at ground control.

The pump discharge was distributed to the six particulators through a thermally insulated manifold-boom (Figure 1b). Variable restrictors placed in each particulator liquid supply line assured equal liquid distribution to all six particulators. Flow in excess of an amount that could be handled by a single particulator would result in a build-up of the liquid inventory in the rotating sleeve. If allowed to go unchecked, this condition could result in the destruction of the particulator.

Figure 3a. Glycerine storage at staging area on top of Muddy Creek Mountain.

Figure 3b. Transfer pump for loading heated glycerine into helicopter.

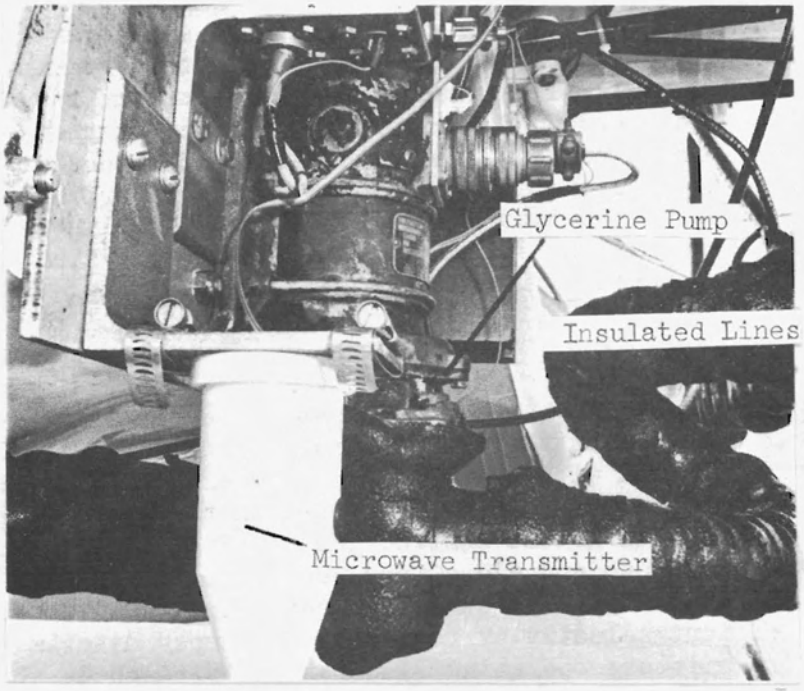

Figure 4a. Speed-controlled, positive displacement pump mounted on helicopter tank.

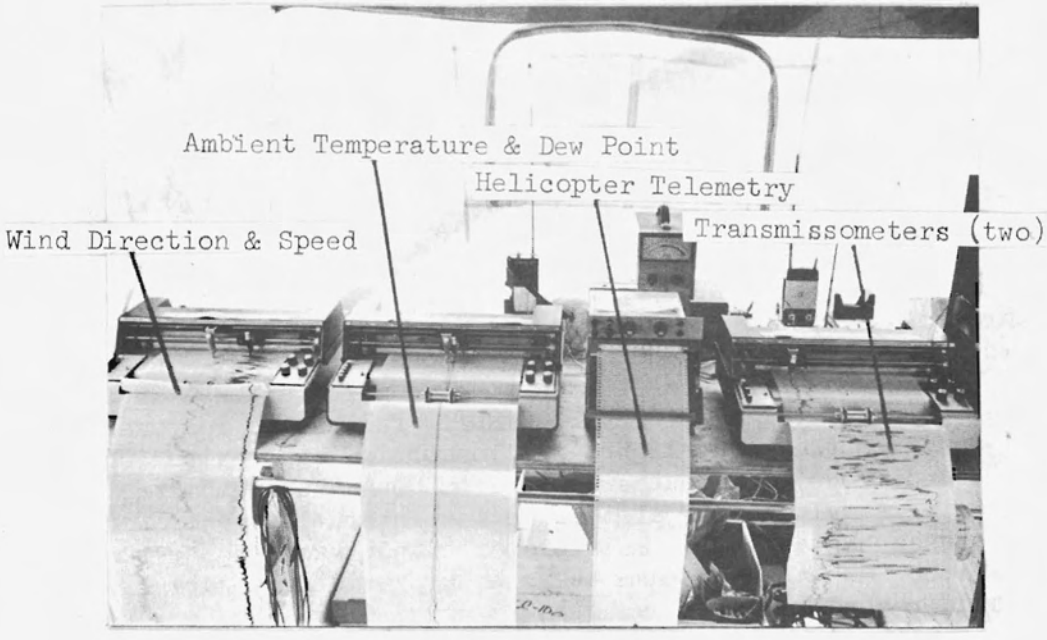

Figure 4b. Recording equipment located at the ground control center.

e. Helicopter Telemetry. A tachometer signal was derived from the liquid transfer pump speed controller and coupled to a ground recorder through the 1.68 GHz marker link (used for navigation and targeting). The ground recorder produced a record of the pump discharge rate throughout the experimental period. The glycerine temperature in the tank, glycerine temperature at an outboard particulator, and the electrical load to each particulator motor were independently measured and data linked through a time shared 173 MHz telemetry system to ground recording equipment (Figure 4b).

2. Targeting and Navigation Support System

a. Microwave Theodolite. A Weather Measure Corporation RD-65 Rawinsonde receiver was used as the primary tracking device. Angular discrimination was achieved with a one meter diameter parabolic antenna (Figure 5a). The antenna was pedestal mounted in the target area and remotely operated from the ground control center (Figure 5b). Angular resolution (both azimuth and elevation) was approximately 0.2°. The receiver frequency response was tuneable from 1.60 to 1.80 GHz and had sufficient selectivity to permit frequency discrimination between three transmitters operating simultaneously slightly above, on, and below the 1.68 GHz center frequency.

b. Tethered Balloons. Two separate tethered balloons were employed in the Greenbrier Valley experiments. Both ballons and support facilities were identical; however, the function of the instrument package on each balloon was different. Two orange, 5.5-foot diameter, helium-filled balloons were suspended from 700-foot long, 20 gauge (110 pound test) nylon lines. The length of each line was calibrated and identifying markers were placed at 10 ft. intervals along the lines.

The instrument package supported by the primary balloon (B-1) contained (1) a cup anemometer for measuring wind speed, (2) an omni-directional photo sensor to measure ambient light, (3) electronic circuitry to provide zero and reference signals along with a multiplexer for signal time sharing and (4) a 1.68 GHz marker-telemetry transmitter. The cup anemometer was designed to provide low threshold response ($\lesssim$ 0.2 mph) and its range was calibrated against two different types of commercial wind anemometers. The ambient light photometer was calibrated to give zero response in a dense fog near ground level at 0700 - 0800 EDT. Full scale response was adjusted to the stray light level occurring at sunrise (under clear sky conditions). Output signals from both the anemometer and photometer were multiplexed along with the internally generated zero and reference signals. The multiplexer output was used to pulse-modulate the 1.68 GHz marker transmitter, thus providing a data link to the ground recording instruments.

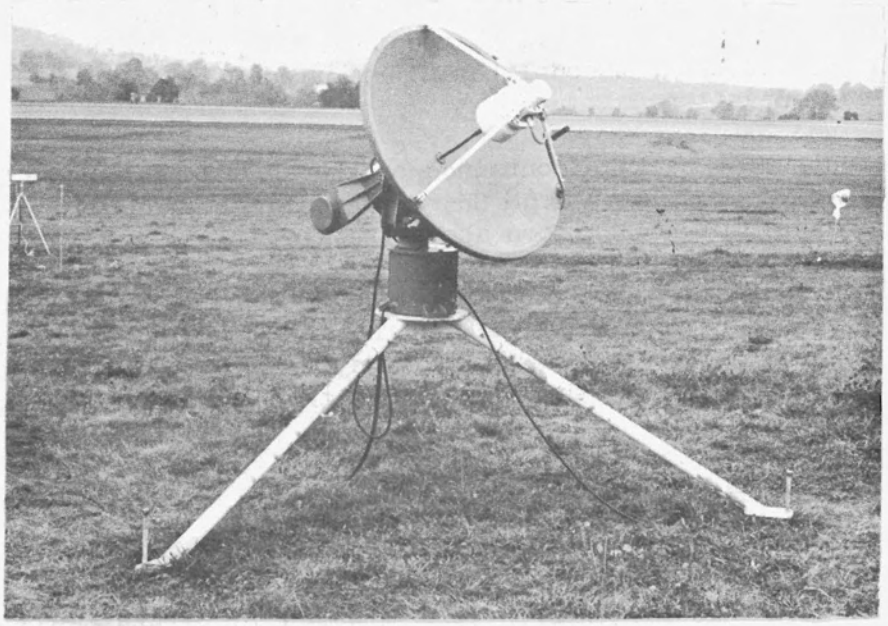

Figure 5a. Theodolite antenna mounted in target area.

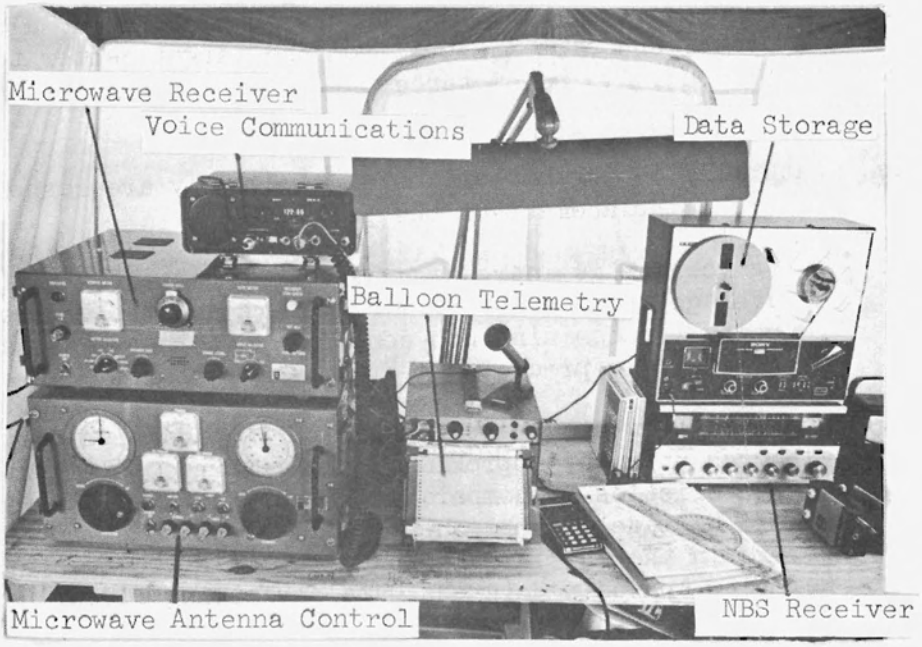

Figure 5b. Theodolite control and communication equipment located in the ground control center.

The B-1 ground tether point was located at the base of the theodolite antenna. The off-set azimuth due to shear wind drift was measured with the microwave theodolite and reported as wind azimuth at the balloon elevation.

The instrument package contained on the second balloon (B-2) provided only a pulse-modulated 1.68 GHz marker signal which was used to verify the location of the balloon above the fog.

c. Helicopter Navigation Marker. A 1.68 GHz marker source attached to the helicopter provided a back-up navigation aid for "homing" on the target area in the approach from Muddy Creek Mountain. The marker also served to verify the location of the helicopter during the seeding operation.

d. Calculating Aids

1) A scaled diagram of the Greenbrier Valley Airport was used as the targeting work sheet (Figure 6). All physical barriers which imposed constraints upon free movement of ground personnel were identified on the worksheet. A line representing true north was drawn through the target area (the microwave theodolite antenna occupied a position on the line) and all azimuth data were referenced to that line.

2) A family of curves similar to those employed by Papania (4) were used to provide the relationship between wind speed, altitude of the fog tops, and distance out from the target center to release point (Figure 7). The distance out calculations were based on the following assumptions:

a) Naturally occurring horizontal winds only are responsible for lateral displacement of the particles.

b) The glycerine is introduced as a mono-dispersed particle with an average diameter of 50 micrometers and the sedimentation velocity (recognizing non-conformity in the upper particle size range) is predictable from Stokes' Law.

c) The time-growth characteristics of the additive particles, although unknown, approximate the vapor deposition time-growth characteristics of comparably sized urea (5). Adjustments should be made in subsequent field tests to compensate for any errors in the initially assumed particle growth characteristics. Refer to Appendix G (gross data on falling glycerine particles).

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[4] Papania, Ralph, Jr., "Field Test of Warm Fog Dispersal System to Support Marine Corps Helicopter Operations," AD-752046.

[5] Smith, Theodore B., et. al., "Warm Fog Modification Studies," AFCRL-71-0467.

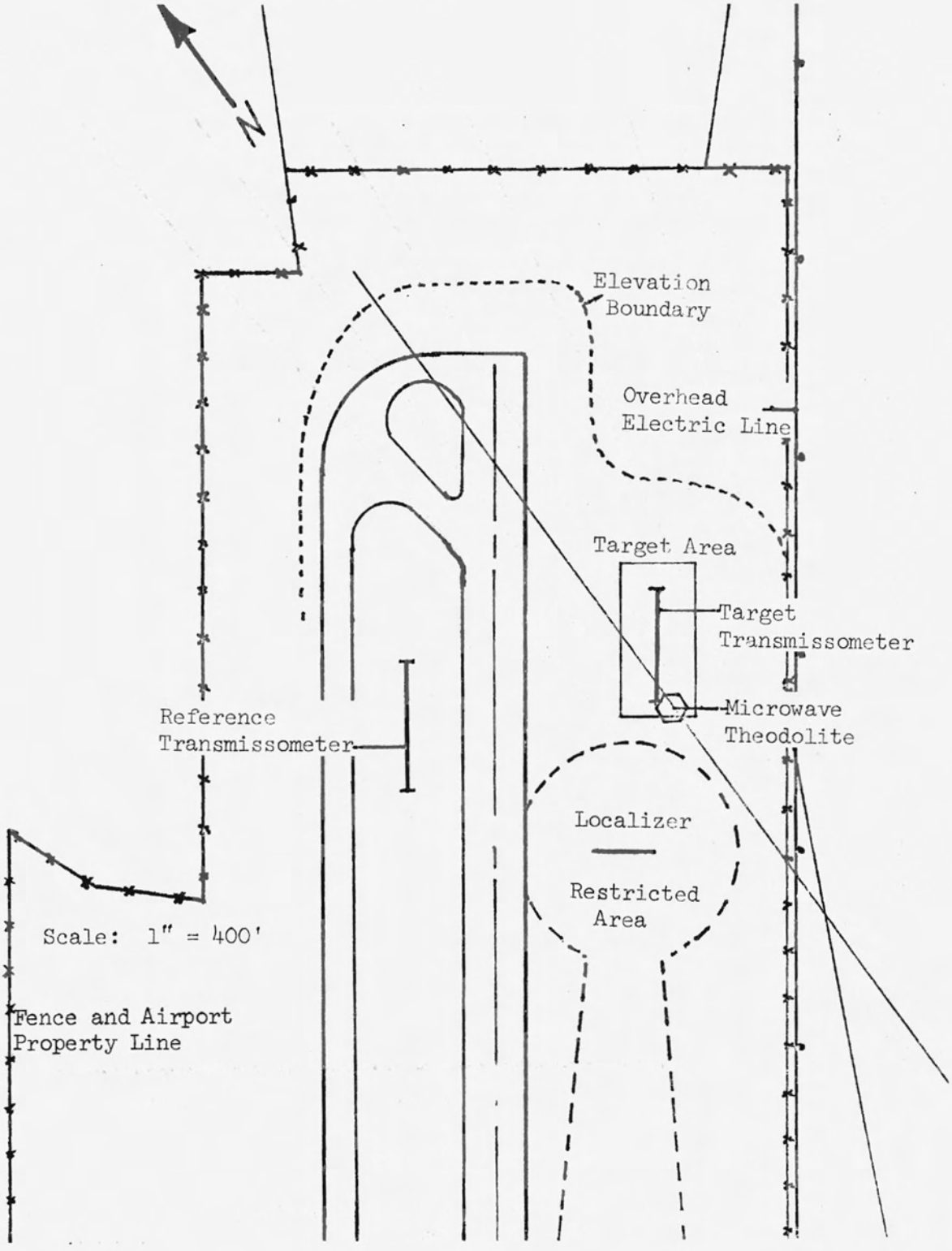

Figure 6. Targeting Work Sheet

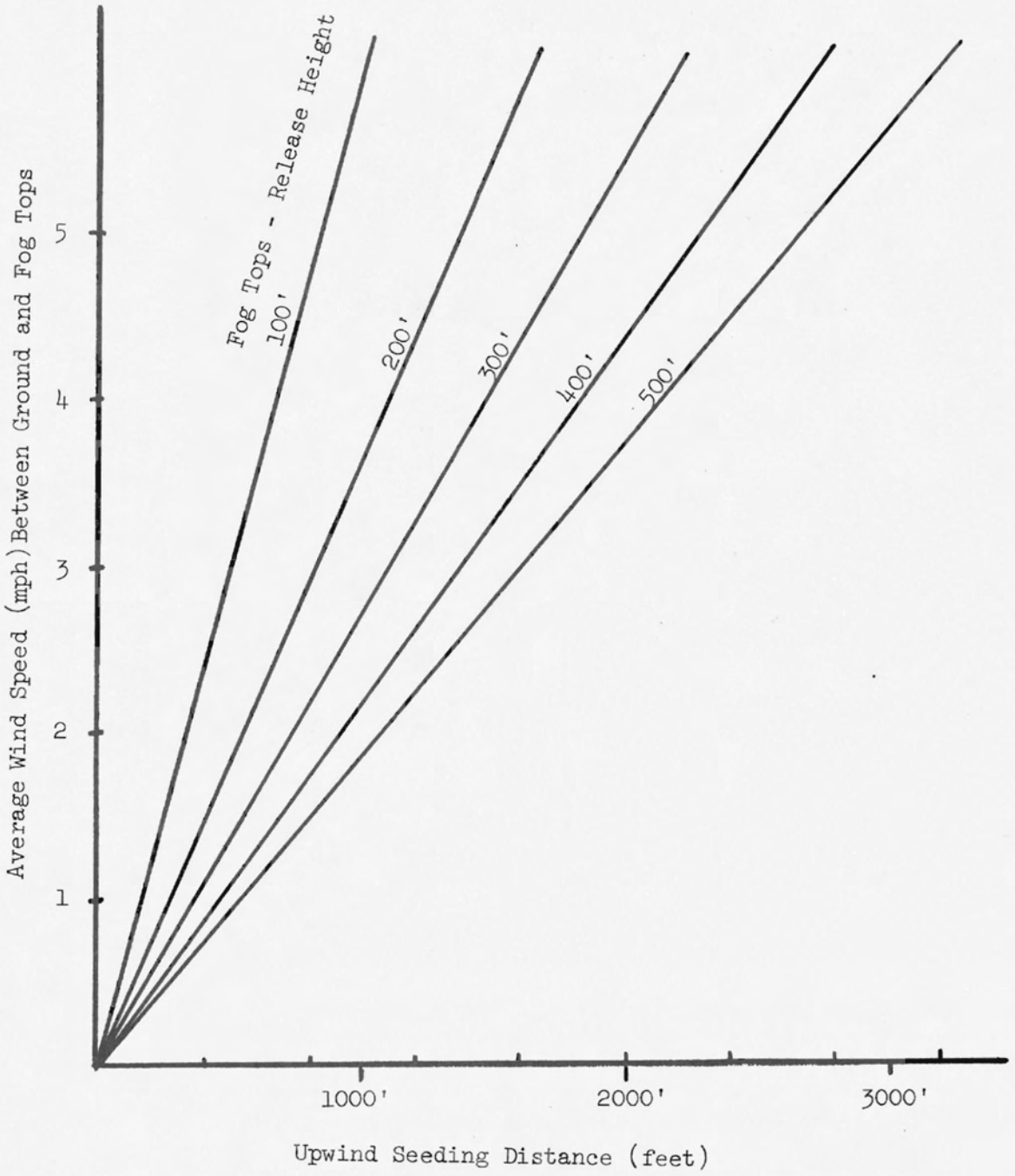

Figure 7. Nomogram for estimating seeding orbital offset distance from target area.

3. Analytical Instrumentation

a. Transmissometers. Two Dow-developed transmissometers were used to measure the visibility at ground level (Figures 8a and b). The transmissometer source contained a single "simple lens" collimator while the receiver unit, other than detector, contained no light gathering optics. The level of mechanical integrity thus required to maintain the optical systems of conventional transmissometers was significantly reduced. The camera tripod mount used on the receiver and slightly more stable mount used to support the source were direct benefits from this improvement. One transmissometer was located in the primary target area and the second transmissometer, the reference transmissometer, was located on a 280° azimuth, 700 feet from the target area as in Figure 6. Both transmissometers were connected to a dual trace analog strip-chart recorder located in the control center and the recorded format was Percent Transmission vs. Time.

b. Time Lapse Photography. Five 2' x 3' "visibility" markers were erected on a line parallel to the transmissometer optical path in the target area (Figure 9a). The cameras were located (in line with) 100 feet from the No. 1 marker and all subsequent markers were spaced 100' apart. A clock was placed in the field of view for time annotation. Each marker was illuminated with a 250 watt (blue) photoflood source. Two cameras were used to record the results: (1) Bauer, Model C-6, 8 mm equipped with a "TrickSet" intervalometer, (2) Pentax, 35 mm SLR with f2.8, 135 mm lens and 2X converter.

c. Collection Slides. Standard 25 x 75 mm microscope slides were coated on one side with Teflon tape and identified with a number. The slides were distributed throughout the anticipated impaction area immediately prior to each experiment. The slides were held in a horizontal position approximately one foot above the earth surface (Figure 9b). The slides were collected after each experiment and evaluated on a standard 100X laboratory microscope equipped with a mechanical stage (Figure 10a).

d. Ground-Level Wind and Temperature/Dew Point Instruments

1) Wind Speed - Weather Measure Model W-103 low threshold cup anemometer equipped with a "3L" light weight cup assembly. The threshold of response was 0.6 mph with an overall accuracy of ± 1%.

2) Wind Direction - Weather Measure Model W-104 wind vane. The threshold of response was 0.75 mph with an overall accuracy of ± 1.5%. The wind transducers (sensors) were mounted 22 feet above ground level at the control center (Figure 10b). The wind data was recorded on a dual channel, analog strip-chart recorder.

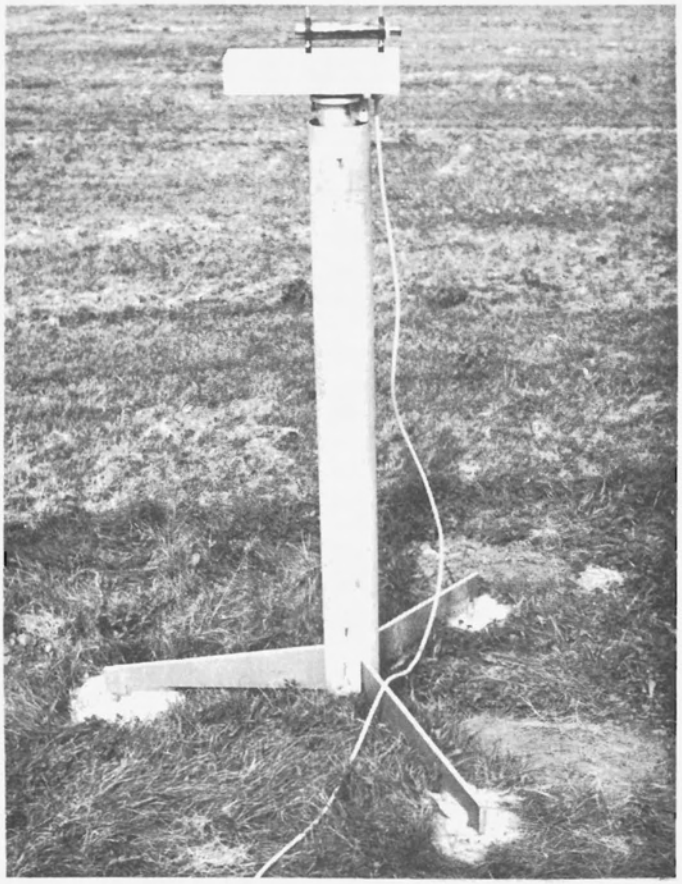

Figure 8a. Portable transmissometer-laser source assembly. Note footing.

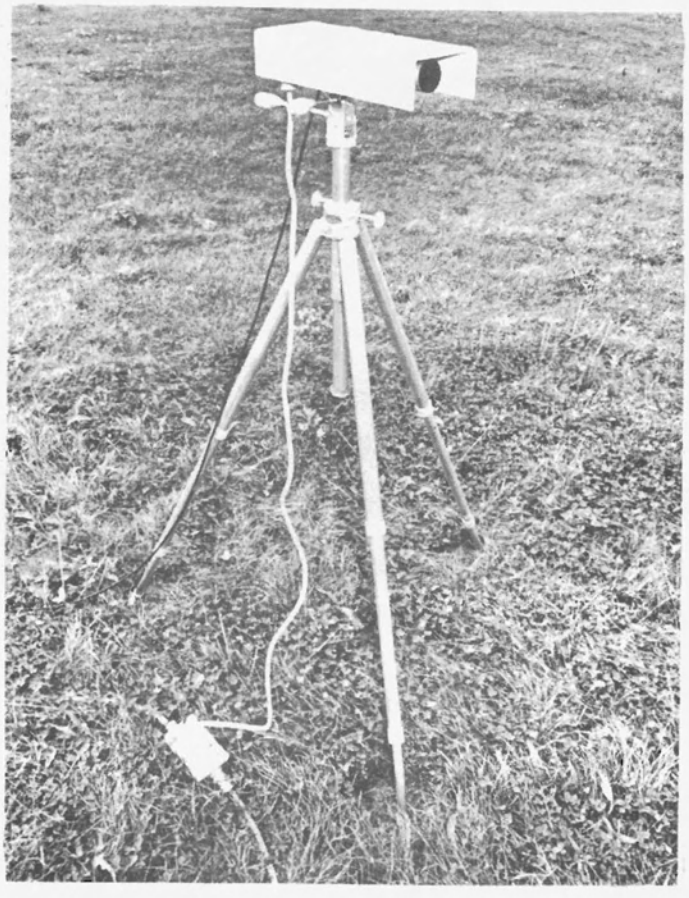

Figure 8b. Portable transmissometer-receiver assembly. Note camera tripod support.

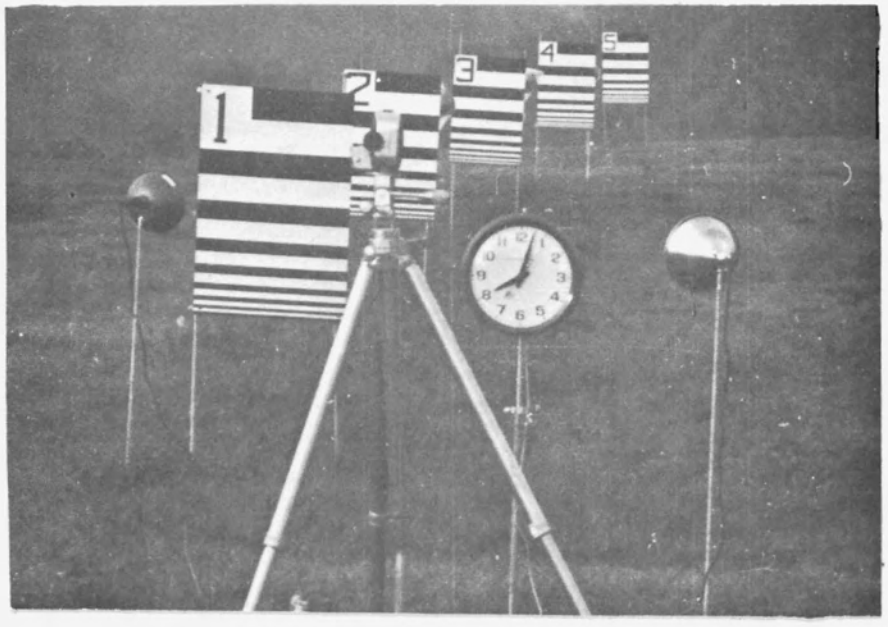

Figure 9a. Time lapse photographic visibility markers erected on a line through the target area.

Figure 9b. Collection slide used to sample fall-out resulting from seeding operation.

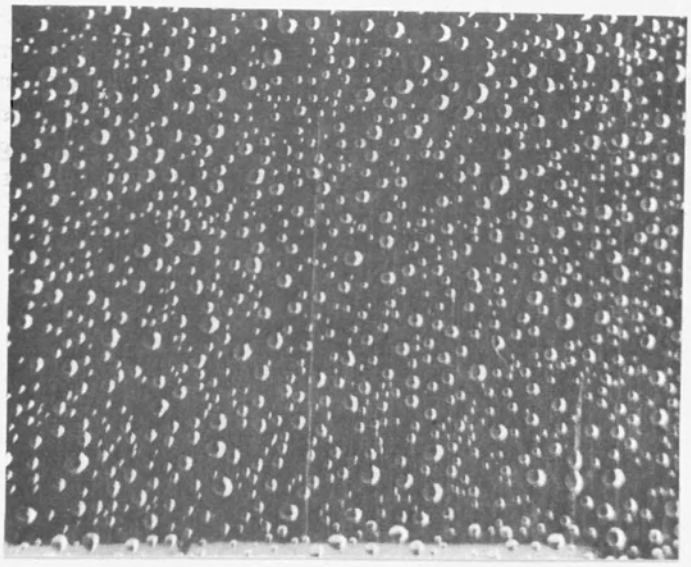

Figure 10a. 4.38X photomicrograph of collected particles.

Figure 10b. Ambient transducers located on pole 20' above ground level at ground control center.

3) Ambient Temperature and Dew Point - A modified Cambridge Systems Model 880 dewpoint hygrometer equipped with a Model 110A aspirator assembly was used to provide a continuous record of the ambient temperature and dew point. The modified system provided a linearized response of both the dew point and ambient temperature over the range of -10° to +40°C with a tracking accuracy of <0.2°C. The aspirator assembly (containing sensors) was mounted 20 feet above ground at the control center (Figure 10b). The temperature and dew point data were recorded on a dual trace, analog strip-chart recorder.

FIELD TESTS

Test No. 1 - September 16, 1973.

0700 - At 0220 a 2.6°C drop in both the ambient temperature (10.24° to 7.5°C) and dew point (10.1° to 7.5°C) was accompanied by a drop in visibility (>95% of maximum clear air transmission T to 0% T). Visibility has remained zero with the ambient temperature tracing 0.1°C below the indicated dew point. The average wind speed varied from 0 to 4 mph on a 018° ± 20° azimuth throughout the period.

0835 - Visibility remained zero at ground level, wind 2 mph at 018°, fog tops 300 feet AGL. Both the ambient temperature and dew point were holding constant at 8.5 ± 0.1°C. Airport authorities notified of pending test.

0845 - Marker balloons in position at 300 feet AGL. Helicopter pilot over target area could not see marker balloons. Balloons elevated to 500 feet AGL.

0855 - Pilot reported "effects of helicopter downwash on fog difficult to estimate" due to very poor visibility (haze) on top. Helicopter entered the fog at 480 feet AGL. Neither ground observers nor transmissometers could discern any effect from downwash.

0905 - Helicopter positioned in a 500-foot circular seeding pattern 1000 feet out from B-2 on a line formed by the marker balloons (Figure 11).

0930 - Seeding began. Glycerine temperature in tank was 51.5°C, temperature of glycerine discharged into outboard particulator was 27.5°C.

0934 - Helicopter moved to new seeding position 1000 feet out from B-2 on 45° azimuth (from line formed by marker balloons as in Figure 11). Temperature of glycerine in tank was 51°C and temperature of glycerine feed to outboard particulator was 35°C. The work rate on all six particulators held constant with two units (No. 4 and No. 5) indicating slight imbalance in load.

0936 - Helicopter moved to new location 1000 feet out on 90° azimuth from B-2 (Figure 11). Analytical transmissometer indicated 5-10% improvement in visibility, reference transmissometer also indicated slight improvement in visibility.

0940 - Telemetry indicated liquid load depleted (seeding complete). Telephone communication reported "top of Muddy Creek Mountain covered with fog."

0942 - Ground observers reported "overhead clearing" and fallout in target area. Analytical transmissometer continued to show improvement in visibility (maximum response 10-12% above reference). Helicopter pilot at 1900 feet AGL could see effects of seeding pattern (depressions in fog) but could not discern ground targets through the holes.

0944 - Isolated areas of varying visibility moved through the test zone (transmissometer verified). Reference transmissometer began to show increased visibility (Figure 12).

0951 - Transmissometers indicated general natural break-up at ground level. Experiment terminated.

TABLE 1

SUMMARY OF ATMOSPHERIC DATA SEPTEMBER 16, 1973

Time, EDT	Altitude, Feet AGL	Wind Speed, mph	Wind Azimuth Degrees True North	Altitude Fog Tops, Feet AGL	Temperature, °C 20 Feet AGL	Dew Point °C 20 Feet AGL
0735-0739	100	3	--	>100	7.9	8.0
0741-0743	200	3	029	>200	--	--
0744-0745	300	3	020	>300	7.9	7.9
0747	368	-	--	368	--	--
0747	400	3.5-4.0	045	<400	--	--
0803	400	3.5-4.0	013	<400	8.1	8.1
0805	375	3.5-4.0	--	>375	--	--
0810-0832	300	2.5-3.0	015	375-400	--	--
0835	22	1.0-1.5	015	----	8.25	8.25
0900	22	0.5	332	----	8.5	8.5
0930	22	0.5	082	400-550[1]	9.0	9.0
0945	22	1.5	157	----	--	--
1000	22	1.5	017	----	9.6	9.6

[1] Altitude reported by helicopter.

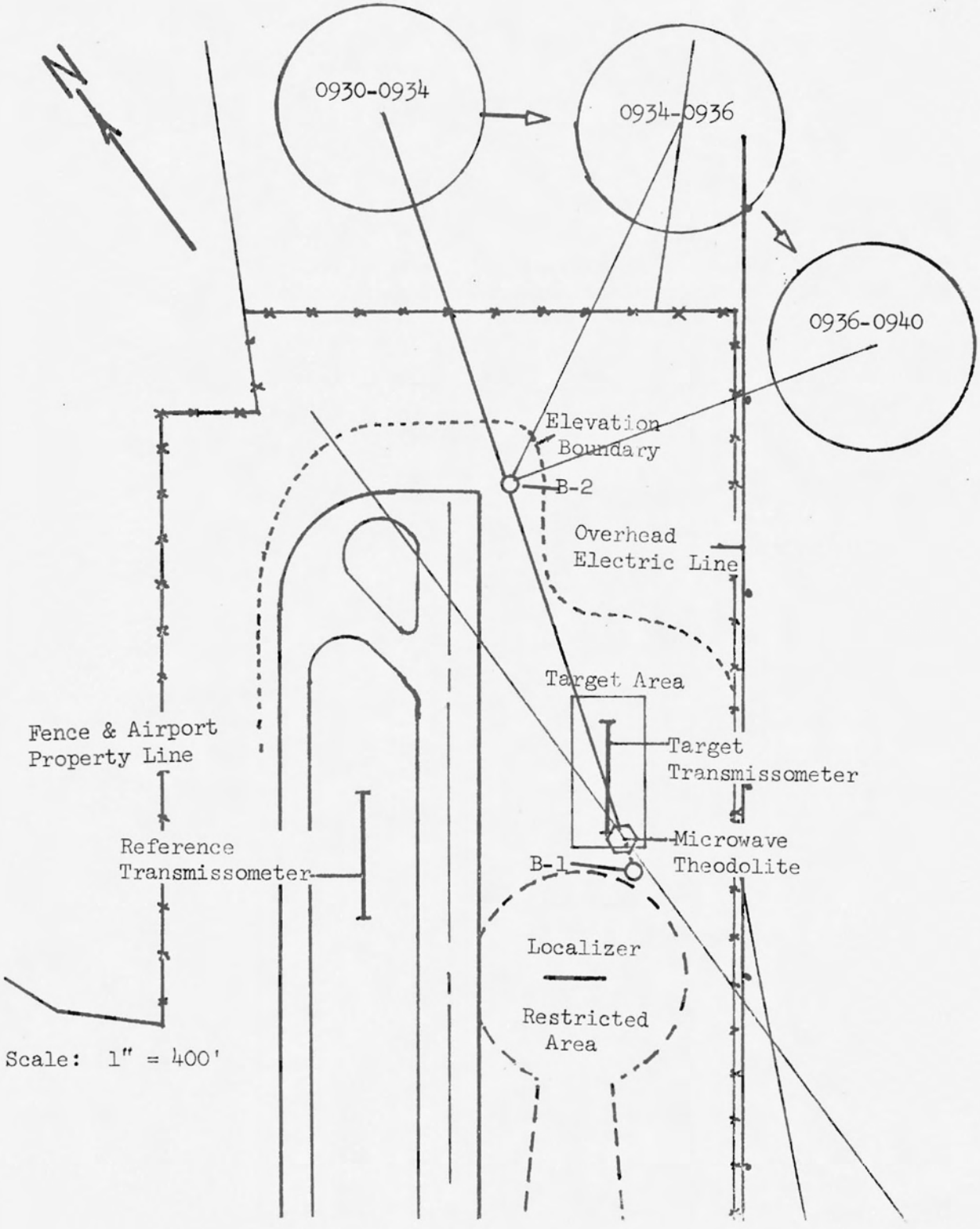

Figure 11. Test No. 1 Schematic

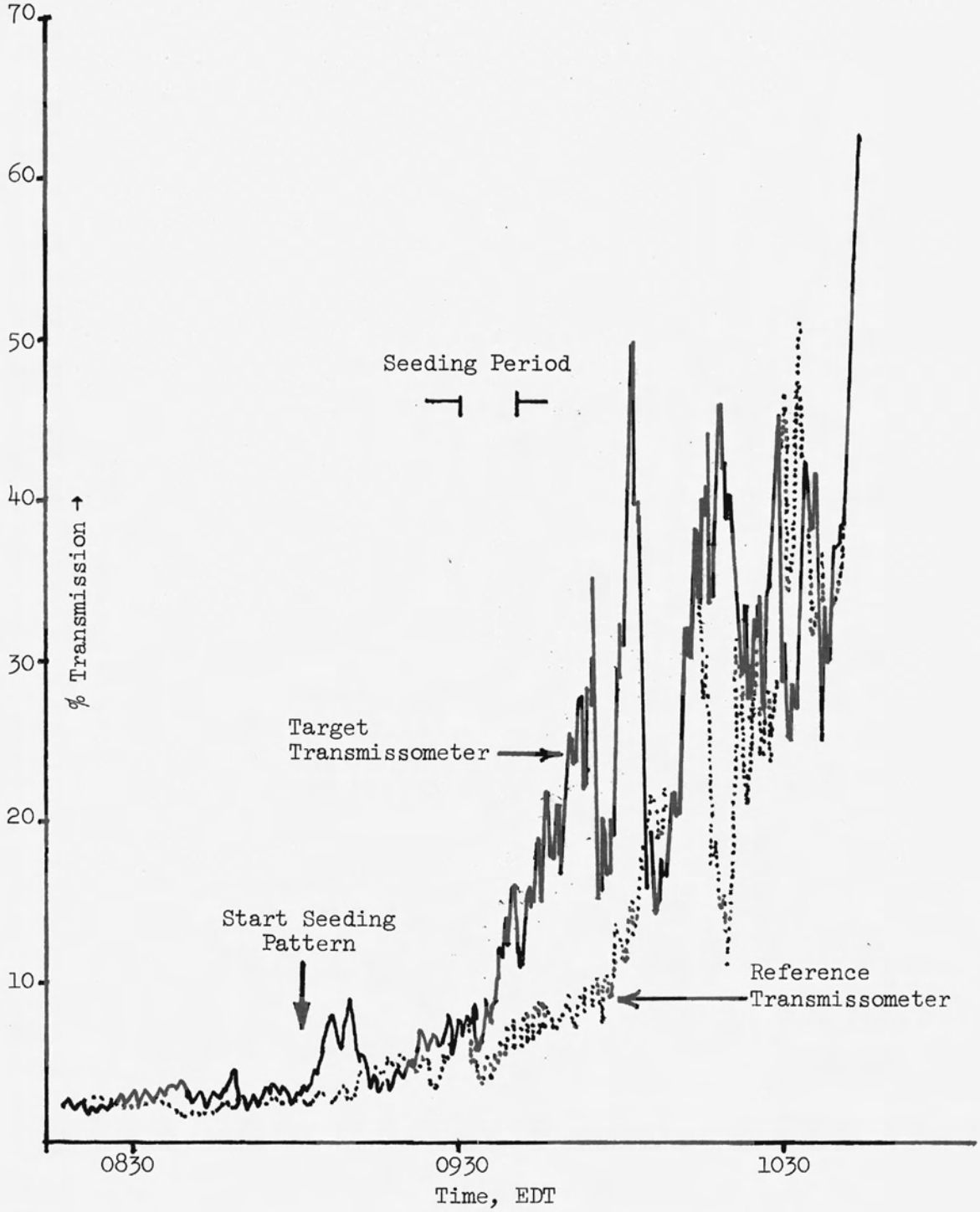

Figure 12. Test No. 1. Transmissometer Records

Test No. 2 - September 19, 1973.

0700 - Following a downward trend, the ambient temperature coincided with the dew point (6.5°C) at 0300. At 0340 both transmissometers indicated a drop in visibility (95% to <5% T). Throughout the period following to 0700, the ambient temperature tracked the dew point within ± 0.1°C, both transmissometers indicated visibility variations between 0-100%, the wind speed varied between 0 and 2.5 mph over a 0 - 360° azimuth (through all four quadrants).

0730 - Both transmissometers indicated near zero visibility since 0700, wind was 2.5 mph at 010° ± 10° azimuth. Both ambient temperature and dew point were holding constant at 4.5°C, fog tops were 150 feet AGL.

0800 - Marker balloons were in position--B-2, 1000 feet out on 020° azimuth at 200 feet elevation. Helicopter pilot had acquired marker balloons, reported that fog was very fine--rotor downwash had noticeable effect on fog tops. Helicopter was flying a 500-foot diameter circular pattern around B-2 (see Figure 13).

0814 - Seeding began. Telemetry indicated all helicopter seeding equipment was functioning normally. The seeding rate was 8.0 gallons per minute.

0818 - Pilot reported seeding operation produced a large hole in fog--ground targets were visible through the hole--the ground was not visible in the surrounding area. Target transmissometer indicated 10-15% improvement in transmissivity. The reference transmissometer indicated no change. Wind was holding constant at 2.5 mph on a 360-017° azimuth.

0824 - Glycerine supply depleted, seeding complete.

0827 - At 1700 feet AGL, pilot could see large hole in fog--and could see cars in parking lot (at control site). Target transmissometers indicated ~ 15% T.

0831 - Helicopter pilot indicated that the hole in the fog at release point was no longer visible. Target transmissometers indicated ~ 15-20% improvement in transmissivity. Test completed.

Table 2

SUMMARY OF ATMOSPHERIC DATA SEPTEMBER 19, 1973

Time, EDT	Altitude Feet AGL	Wind Speed, mph	Wind Azimuth Degrees True North	Altitude Fog Tops, Feet AGL	Temperature, °C 20 Feet AGL	Dew Point, °C 20 Feet AGL
0700	22	0	360	--	4.5	4.5
0735	150			$\leqq$150		
0737	150			$\leqq$150		
0743	150		010			
0747	200	2.0				
0758	22	2.2	360	150-200		
0806	300		060		3.7	3.4
0814	22	2.2	024			

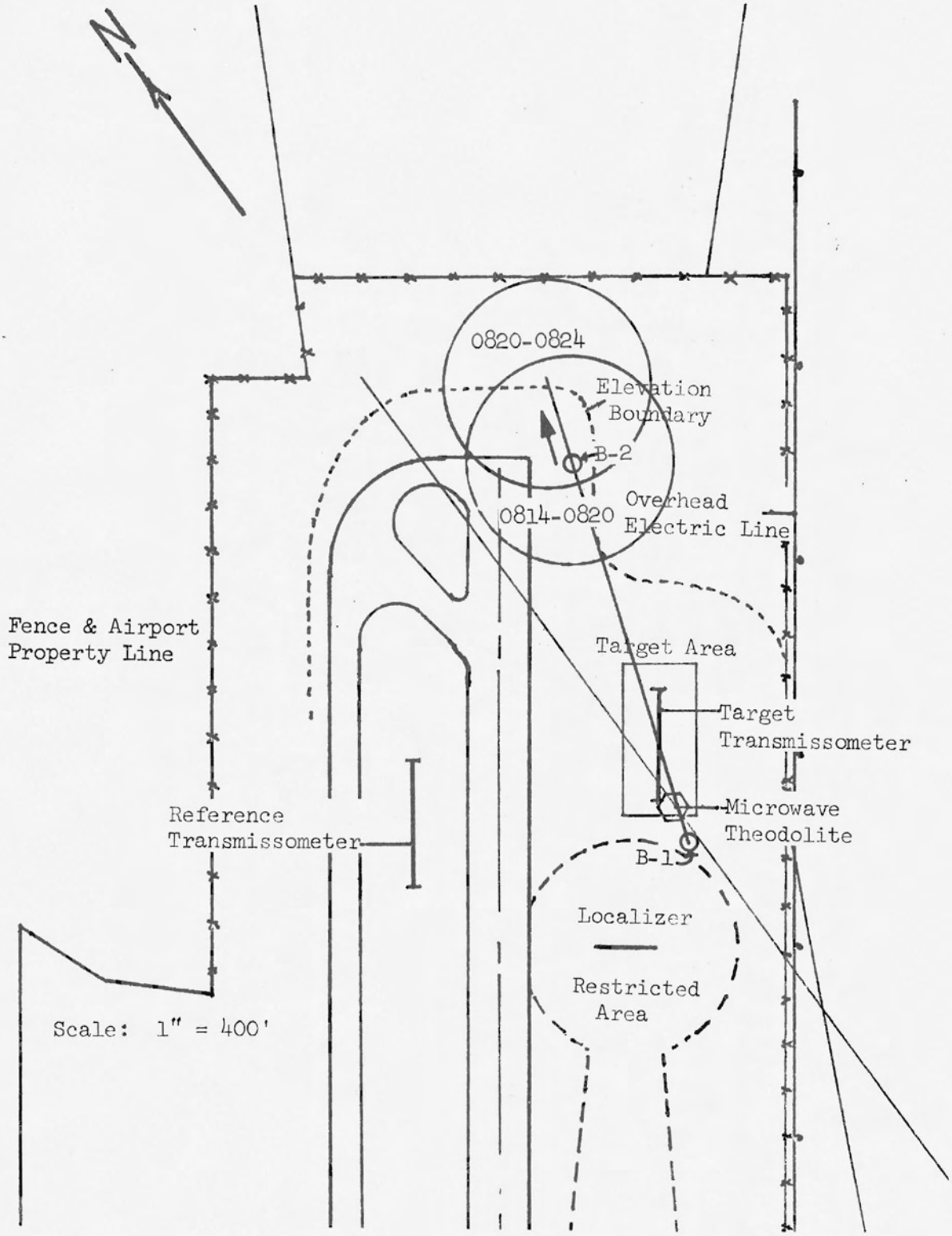

Figure 13. Test No. 2 Schematic

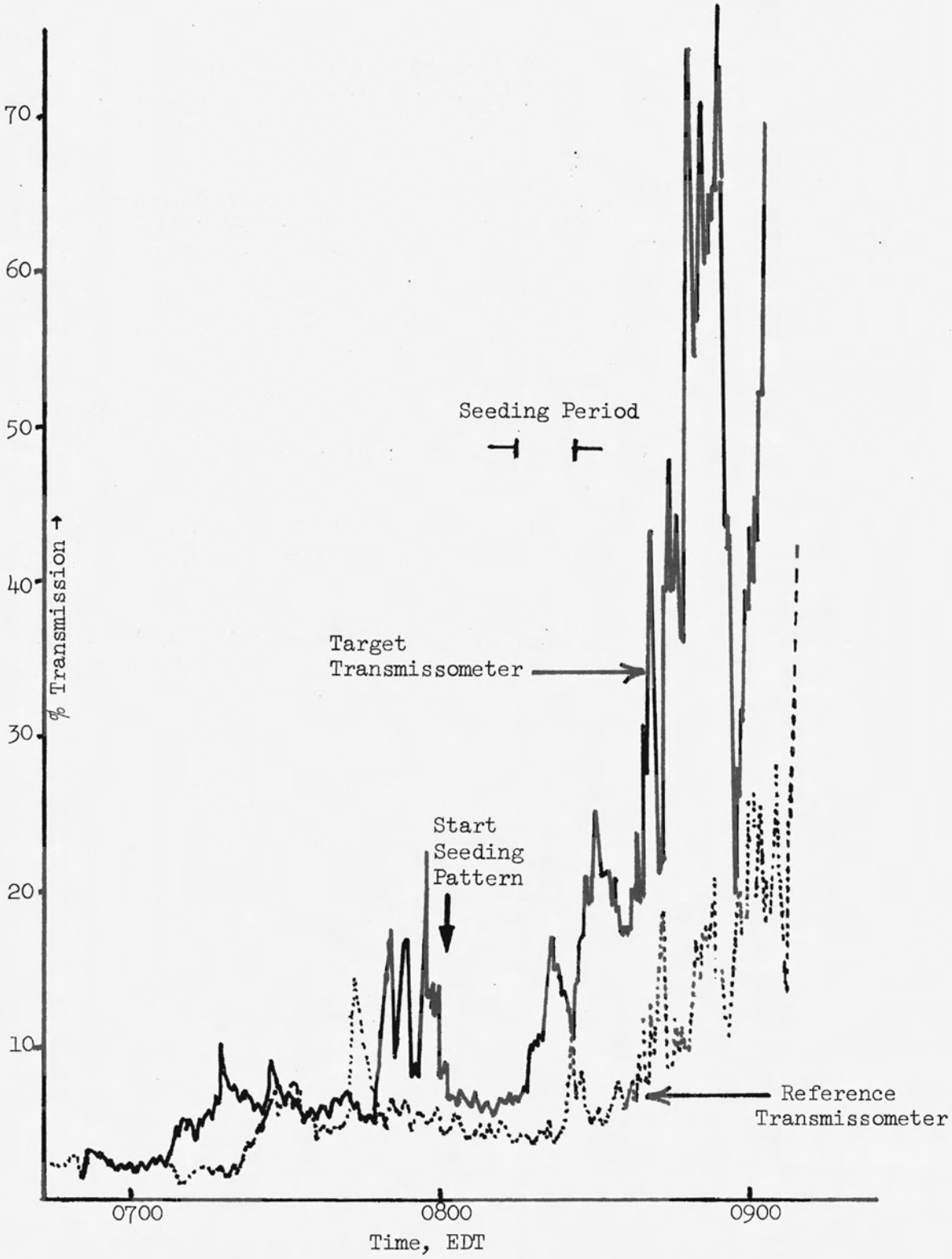

Figure 14. Test No. 2. Transmissometer Records

Test No. 3 - September 20, 1973.

0700 - At approximately 0030 both transmissometers indicated a drop in visibility from >95% to <5% T. Throughout the period following, visibility varied between 0-90% T, the wind speed varied between 0-4 mph on 360-180° azimuth (quadrants I and II).

0720 - Both transmissometers indicated 0-20% T, decision was made to proceed with test. Average wind speed at 200 feet AGL was 3 mph on 193° azimuth. B-2 marker balloon was positioned 1100 feet out on 193° azimuth at 200 feet AGL.

0810 - A change in wind azimuth necessitated relocation of B-2 to new position 1000 feet out on a 235° azimuth. The helicopter began flying a 500-foot diameter circular pattern around B-2 (see Figure 15).

0820 - Helicopter pattern was moved 300 feet east of B-2 (225° azimuth) to correct for wind change (from 210-255° azimuth at 0810 to 180-210° azimuth at 0820). Both transmissometers began to show improved visibility at ground level.

0826 - Seeding began (communication mix-up resulted in helicopter seeding pattern around B-2 (235° azimuth). Telemetry indicated seeding equipment was functioning well.

0830 - Attempts to relocate helicopter 1700 feet out from target area on 220° azimuth resulted in new position 1000 feet out on 040° azimuth due to faulty communications.

0833 - Helicopter was positioned 1700 feet out on 235° azimuth.

0835 - Helicopter azimuth changed to 225° (distance out remained at 1700 feet).

0836 - Telemetry indicated glycerine supply depleted. Seeding complete.

0837 - Helicopter pilot reported that runway was clearly visible in the seeded area and that he could not see ground on either side or off either end of runway.

0844 - Helicopter pilot reported general break-up of fog throughout the entire area. Both transmissometers indicated wide variations (10-80% T) in visibility at ground level. Test concluded.

Table 3

SUMMARY OF ATMOSPHERIC DATA SEPTEMBER 20, 1973

Time, EDT	Altitude Feet AGL	Wind Speed, mph	Wind Azimuth Degrees True North	Altitude Fog Tops, Feet AGL	Temperature, °C 20 Feet AGL	Dew Point, °C 20 Feet AGL
0630	50	0-1	031-180	Note 1	Note 3	Note 3
0645	22	0-1	031-180			
0645	100	1-2	-			
0645	200	4	220			
0712	200	1-2	197			
0720	200	3	193			
0720	22	0-1	255	<200		
0740	200	3	190	<200		
0800	22	2	140-255	-		
0820	200	2-3	210	150 (Note 2)		
0820	22	0-3	180	<200		
0824	22	0-2	180	<200		
0900	22	0-2	017	-		

Note 1. Ambient light level too low to make measurement.
Note 2. Altitude reported by helicopter.
Note 3. Temperature and dew point data record not obtained due to malfunctioning recorder.

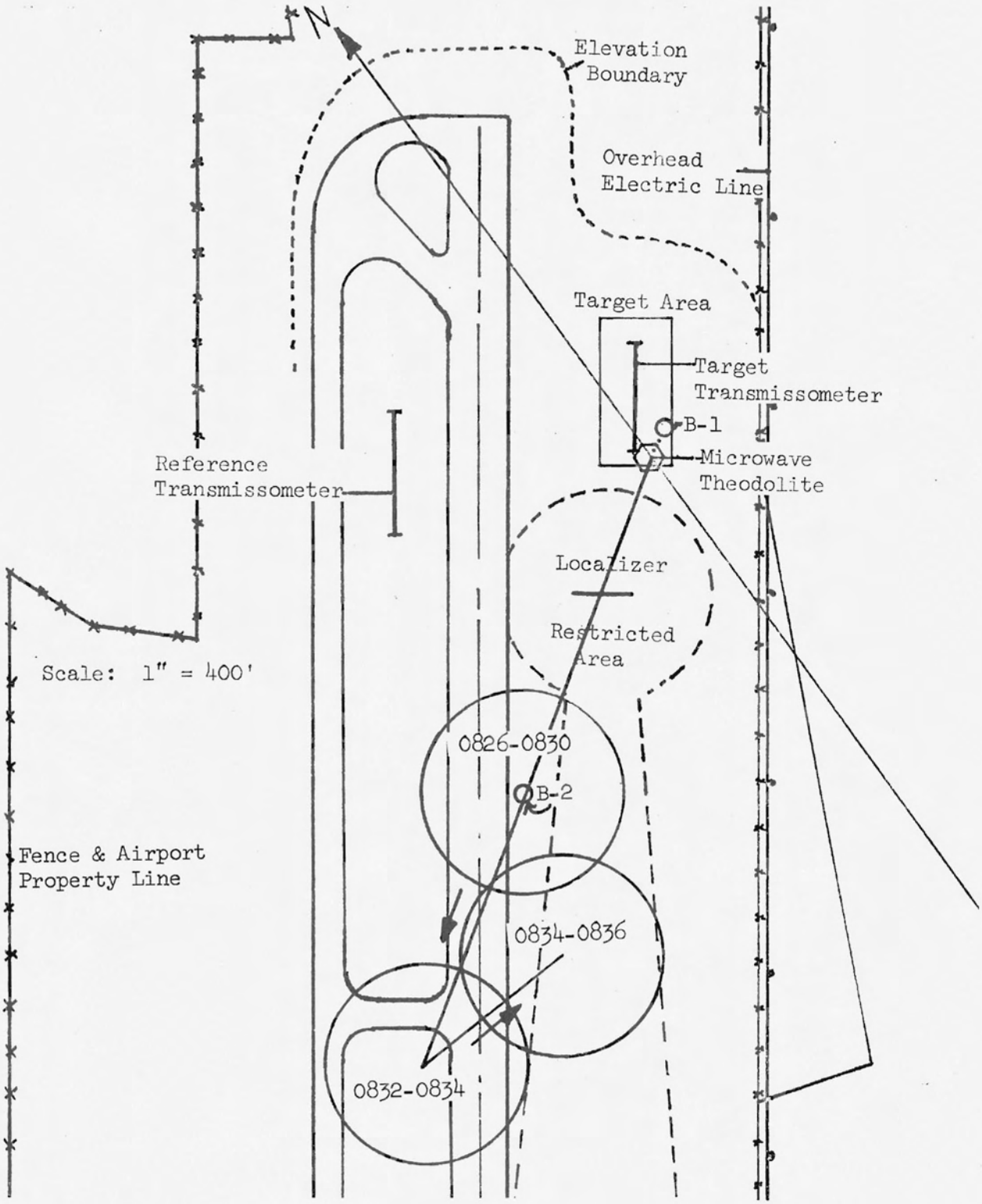

Figure 15. Test No. 3 Schematic

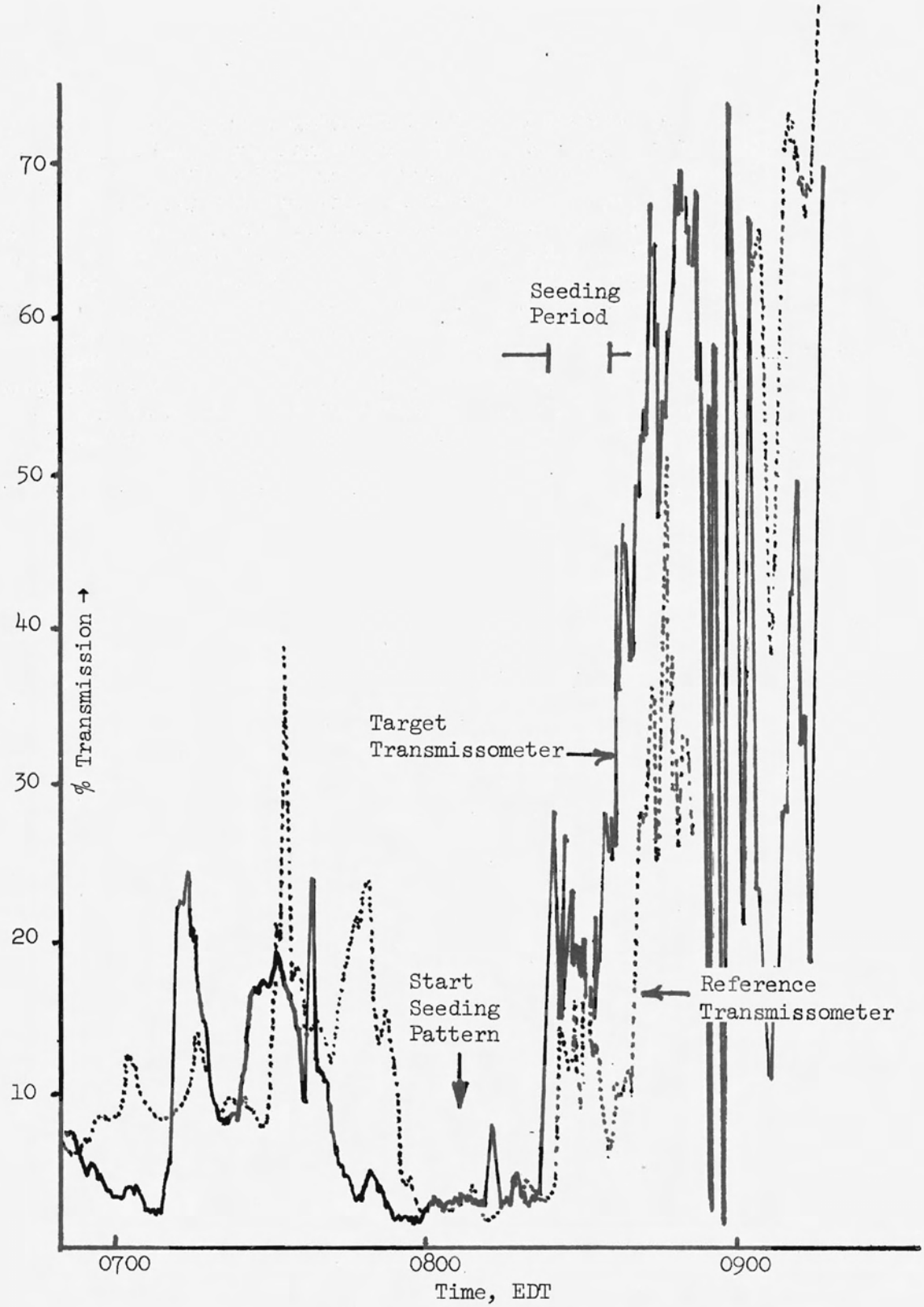

Figure 16. Test No. 3. Transmissometer Records

Test No. 4 - September 24, 1973.

At 0100 an extensive fog developed in the Greenbrier Valley area. The fog persisted throughout the night and at 0700 low visibility conditions on Muddy Creek Mountain precluded a helicopter launch before 0830-0900. At 0830, the electrical heater on the helicopter glycerine tank was disconnected in preparation for a test. The helicopter was launched and shortly thereafter, again due to rapidly deteriorating conditions, the pilot made the decision to return to the helicopter staging area. At 0950 the weather conditions improved sufficiently to permit VFR flight and again the helicopter made an approach to the target area. At 1014 both transmissometers indicated a general improvement in visibility at the test site. The telemetry data indicated that the glycerine temperature in the helicopter tank was marginal (47°C) for safe operation. Subsequently, the test was terminated and the helicopter returned to Muddy Creek Mountain without releasing its load.

Test No. 5 - September 28, 1973.

0830 - Both transmissometers indicated <5% transmission. The ambient temperature and dew point were both at 12°C and increasing at a 1°C per hour rate. The wind at ground level was 0.5 - 1.5 mph on a 360° ± 15° azimuth. The helicopter departed from Muddy Creek Mountain. Prior to launch time, the staging site was "fogged in."

0848 - Helicopter was over the target area and could not acquire marker balloons (tethered at 400 feet AGL). Balloons were raised to 450 feet AGL.

0857 - Pilot reported that fog was beginning to cover Weaver's Knob (see Figure 1). Marker balloons were now below fog tops.

0910 - Marker balloons were raised to 500 feet AGL. Wind at 430 feet was 0-1 mph on a 270° azimuth, at ground, 0.5 to 2.5 mph on a 225° azimuth. The outboard balloon (B-2) was placed 800 feet out on 270° azimuth from the target balloon (B-1) (see Figure 17).

0925 - Both marker balloons were raised to 600 feet AGL. Helicopter was placed in a circular pattern around B-2. Pilot reported that balloons were only visible objects in area.

0927 - Seeding began, pump discharge rate was 8 gallons per minute, telemetry data indicated that spray system was functioning normally.

0930 - Pilot reported that marker balloons were in fog--had to fly a tight pattern around B-2 in order to maintain visual contact.

0935 - Helicopter was moved 300 feet out from B-2 on 270° azimuth.

0936 - Seeding completed.

0938 - Ground observer reported a "definite clearing" in the direction of the target area. Helicopter pilot reported "very little effect" other than a large darkened area around the balloon. Transmissometers indicated only a transient change in visibility at ground level.

0945 - Helicopter pilot reported that sphere of influence from seeding operation was moving northwest--away from the release balloon. Pilot could readily discern a hole in the fog but did not see the ground. Transmissometers indicated little increase in visibility at ground level. Experiment concluded.

Table 4

SUMMARY OF ATMOSPHERIC DATA SEPTEMBER 28, 1973

Time, EDT	Altitude Feet AGL	Wind Speed, mph	Wind Azimuth Degrees True North	Altitude Fog Tops, Feet AGL	Temperature, °C 20 Feet AGL	Dew Point, °C 20 Feet AGL
0627	22	1.5-3	017-336		10.7	10.7
	500	1.5	300			
	600	4	250			
0635-0645	400	3.5	320		10.7	10.7
	300	3.5	010			
	200	3.5	015			
	100	0.5-1.5	015			
0710-0720	22	0.5-2.5	0-035		11.0	11.0
	200	0 -1	005-015			
	300	2.5-3	303			
	400	2.5-3	304			
	500	2.5-3	270			
	600	3 -5	260			
0740-0747	22	0 -1.5	0-035		11.2	11.2
	500	2 -3	265			
	400	2.5-3	310			
	300	2	310			
	200	1	010			
	100	1.5-2	030			
0802	200	2	130	<200	11.5	11.5
0837	200	0 -1	110	<200	12.2	12.2
0855	200	1 -2	110	>200	12.5	12.5
0910	430	0.5-3	270	430	12.5	12.5
0925	450	1	270	>450	13.0	13.0
1000					14.0	14.0

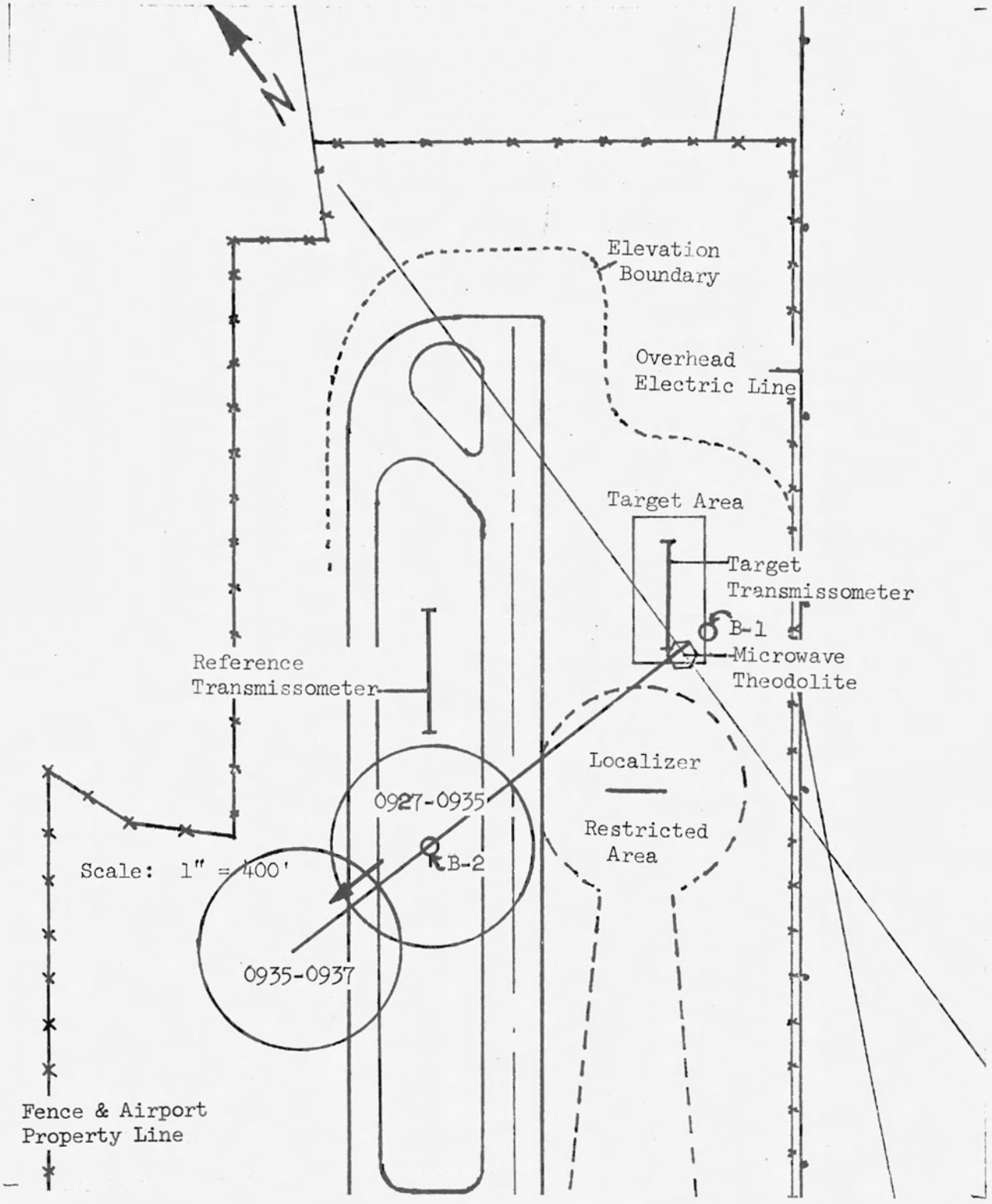

Figure 17. Test No. 5 Schematic

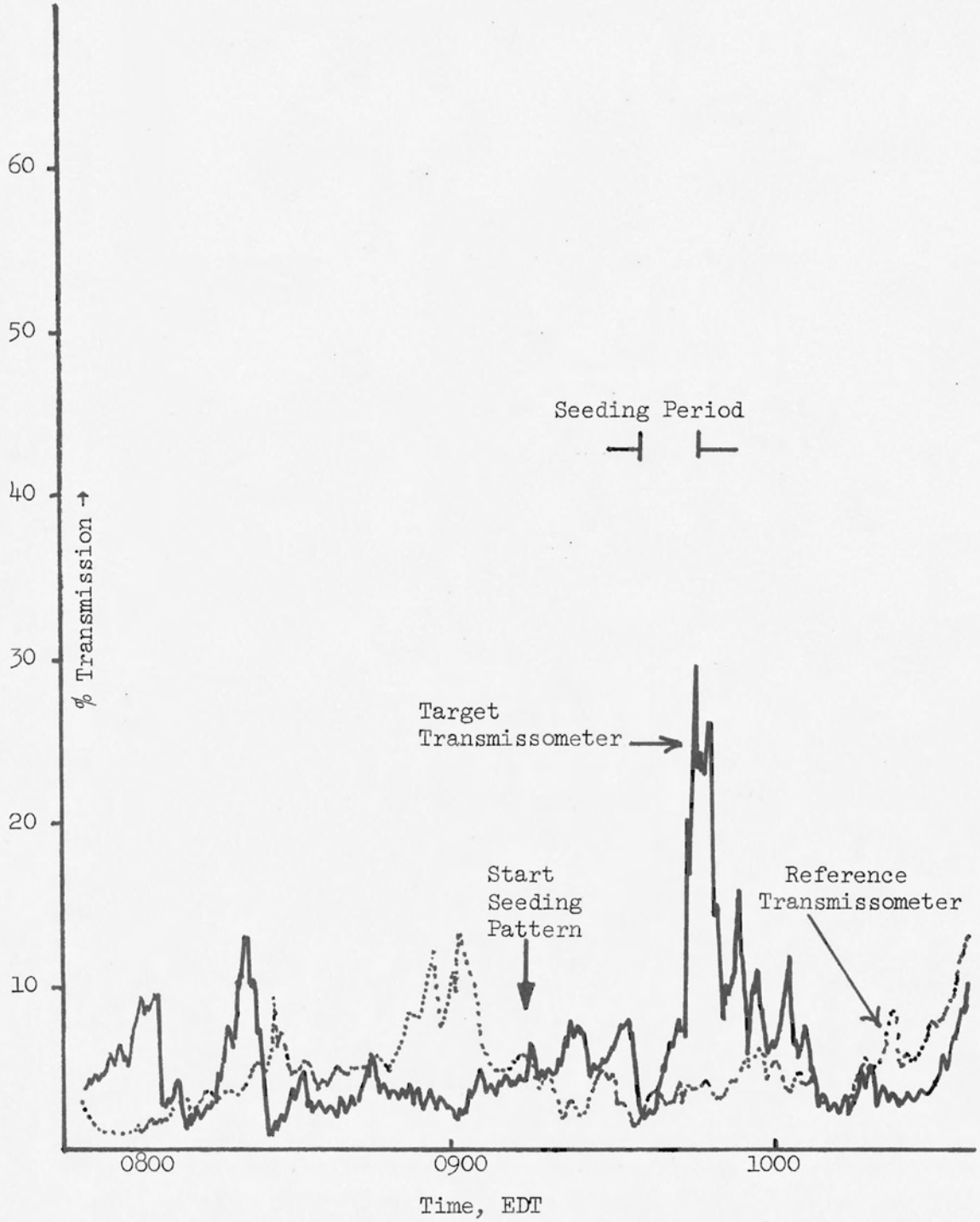

Figure 18. Test No. 5. Transmissometer Records

DISCUSSION OF RESULTS

A review of the wind data obtained on-site during previous testing (3) would indicate the statistical average ground surface wind movement to be ~ 5 mph on a 235° azimuth. However, results from vertical profile wind studies showed that the wind speed normally varied between 0-6 mph with azimuth varying between 360-180° from ground level to the fog tops (i.e., see Appendices A-F). Shear winds changed rapidly, both with time and with altitude. At an eight gallons per minute discharge rate and an 80 gallon payload capability, the seeding time frame was set at 10 minutes. Approximately four minutes were required for the seeded glycerine to reach the ground, therefore a 14-minute period of scatter-stable fog accompanied by quiescent wind activity would be required for a completely satisfactory test. A combination of these conditions was not in existence at any time throughout the test period.

It was anticipated that the freedom of movement afforded by a helicopter would be an advantage in overcoming the targeting problem. For this reason a helicopter was chosen as the delivery vehicle in the Greenbrier experiments. The limited payload capability of the Bell Jet Ranger-II was a trade-off for availability. It was assumed that practical utilization of the glycerine system for clearing fogged-in airports would be dependent upon the availability of on-site delivery vehicles. The Bell Jet Ranger-II falls in the largest class range that would be present at most major civil airports in the United States, therefore a larger vehicle was not considered for use in the Greenbrier experiments.

A circular seeding pattern was employed in all the experiments because it was felt that the best control and maximum effect could be produced by restricting the seeding area to a well-defined geometry (such as a circle). A seeding line would have decreased the targeting problem; however, the effects would have been more difficult to evaluate. Since the reference and target transmissometers were separated by about 600 feet, it is highly improbable that the sphere of influence from a line pattern could have been restricted to only one instrument. The distance separating the transmissometers could have been increased at the additional risk of introducing sampling uncertainties (even at 600 feet separation, natural variations in fog density - percent transmission were noted).

In developing the experiment it was assumed that corrections for normal variations in shear winds could be up-dated throughout the test period. However, an examination of the experimental data tends to discount a high probability of success. For example, in tests No. 1 and No. 5, the release altitude was 500 feet, which requires approximately six minutes for earth impaction. Once released, no further control can be exerted on the particle,

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3 "Climatology of Appalachian Valley Fog at White Sulfur Springs, West Virginia and Near-by Stations During Months of Peak Fog Frequency," Alfred A. Spatola, AFCRL-72-0054.

i.e., its trajectory is governed by shear winds and the control time constant for a 500-foot altitude becomes about six minutes. The data show that variations in wind speed and azimuth during each test far exceed these limits.

In selecting the helicopter staging area on Muddy Creek Mountain, it was assumed that 2900 feet MSL (approximately 650 feet above the runway level) would assure a fog-free environment for originating VFR operations. However, the helicopter site was "fogged in" on two separate occasions. Test No. 1 on September 16 had to be terminated prematurely to allow the helicopter to return when at 0940 the fog tops covered the mountain. Test No. 4 on September 24 was not completed due to a two hour delay in getting the helicopter airborne (during the delay, the glycerine temperature in the helicopter tank dropped from 55°C to 47°C).

The navigation aids and targeting procedure performed their necessary function without fault. The tethered balloons above the fog tops provided an adequate reference for the seeding operation. No difficulty was experienced in maneuvering the balloons into the desired locations. The 1.68 GHz markers provided an easy means of verifying the exact locations of both the marker balloons and the seeding helicopter (during seeding operations). The angular error developed in the theodolite was $<0.2°$ which when translated into distance would be approximately 0.0035 foot per foot out (tangent of angle error). For example, at 1000 feet out from the target area, the maximum error would be equivalent to <4 feet.

The delivery system performance was excellent throughout the experimental period. The air-to-ground data links permitted a real-time evaluation of the glycerine temperature, pump discharge rate, and a load check on each particulator. Prior to conducting a test, the liquid flow-rate to each particulator was adjusted to the same value. It was noted in Test No. 1 that the work rate on two particulators was excessive. A recheck of the flow distribution following the experiment verified that an unbalanced load had developed. The decision to cancel Test No. 4 was based on the telemetered tank temperature of 47°C. It was judged that the pressure drop across the rotating particulator sleeve would not be sufficient to discharge the viscous glycerine; thus possible particulator destruction was averted.

In the field, analytical instruments performed remarkably well throughout the experimental period. Following the initial set up and alignment period, the transmissometer located in the target area was not touched. However, due to a high level of nocturnal animal activity, the more remote reference transmissometer had to be realigned on several occasions--an operation which required about ten minutes to complete. Both transmissometers produce an equal response to a given level of light scatter; however, they had not been calibrated against other instruments (NBS) prior to the experiments. No attempt has been made to relate percent transmission to the human visual system (a subject well covered in literature). The choice of a 300 feet sample path was a compromise. Any increase in the distance separating the source and receiver would correspondingly reduce the probability that 100% of the optical path "1" would fall into the affected (dispersed) zone. Conversely,

any reduction in "l" amounts to a reduction in sample volume and also limits the range of visibility that can be measured. A reduction in sample volume tends to maximize the schleiren effects which are present in all ground-level fogs.

The transmissometer records from tests No. 1, 2, and 5 indicate significant improvements in the percent transmittance in the target area following the seeding periods. The % T improvements appear relatively small; however, when translated into RVR (feet) represent significant improvements in visibility. An examination of the transmissometer records prior to the seeding periods provides a reasonably good estimate of the variations in % T due to natural causes. The variations in % T during and immediately following the seeding periods in tests No. 1, 2, and 5 which exceed the pretest variations by a factor of 2X are considered to be significant. For example, normal variations in % T preceeding test No. 3 would suggest that improvements in the order of 50% T or more would be required for significance.

The expanded scale dew point equipment produced a reliable record of the atmospheric dew point. Each of the twelve fogs occurring between September 6 and October 1 were preceded by converging trends in the ambient and dew point temperatures. Within a period of 30-60 minutes following an intercept of the two curves, the transmissometers began to respond. Special significance was attached to the moisture vapor-liquid equilibria during the natural visibility decay cycle of the fog. It was assumed that the period of natural fog dissipation could be predicted from liquid-vapor equilibria with the same level of confidence as the initiation and growth cycle. Therefore, supporting dew point and ambient temperature data would weigh heavily in deciding the significance of any effect produced by a dispersal test.

The eight gallon per minute seeding rate employed in the experiments was established by equipment limitations and did not represent an estimate of the quantity of glycerine required to open a "fogged in" airport. The experiment plan allowed for controlled reduction in the seeding rate (as test data warranted); however, due to a limited number of workable fogs this objective was not accomplished. A helicopter with an eighty gallon payload capability flying at 25 mph and releasing glycerine at eight gallons per minute would affect a zone 4.2 miles in length. With a required approach zone of 2000 feet, approximately 11 passes could be made. Under the most ideal conditions (static shear winds and fog life cycle in the decay mode) eight gallons per minute or less may be sufficient to accomplish the stated objective. Conversely, a five mile per hour shear wind or a 090° azimuth from the runway would result in a 400 foot displacement of the initial seeding effects during the period of a single seeding pass. Even if the diffusional effects caused by the turbulence associated with shear winds are ignored, it is most unlikely that a single seeding craft could maintain the required opening for a safe landing approach.

CONCLUSIONS

1. The original objective of acquiring sufficient quantitative data in a field evaluation to prove the effectiveness of glycerine as a warm fog dispersal agent was not achieved in the Greenbrier Valley experiments.

2. The choice of an adequate site for field testing cannot be based on a climatological history composed only of (a) days of fog incidents and (b) surface wind data. Fogs at ground level can exhibit considerable variations in the amount of scatter over a 300 feet distance--a phenomenon which is very difficult to discern by visual observation but plays an important role in deciding the significance of experimental results. Shear wind data obtained at ground level only does not produce sufficient information for predicting fallout effects. Wind data must be obtained at varying altitudes throughout the fog and average or weighted values used to calculate seeded droplet movement. Advance knowledge of this data might have eliminated the Greenbrier Valley Airport as a suitable test area for the glycerine experiments.

3. Statements pertaining to probability of success must take into consideration factors other than dispersal efficiency alone. Even though glycerine produced significant reductions in the amount of light scatter and therefore increases in visibility, rapid and unpredictable movements of the sphere of influence tends to discount the probability that the quantity of glycerine (80 gallons) used in the Greenbrier Valley experiments would be adequate (under the prevailing conditions) to open a "fogged in" airport.

APPENDIX A

Wind Data - September 22, 1973

Time, EDT	Altitude, Feet AGL	Wind Speed, mph	Wind Azimuth Degrees True North
0640-0645	50	2.5 ± 1	-
0645-0651	100	2 ± 1	-
0651-0657	200	2.5 ± 0.5	-
0657-0702	300	2.5 ± 0.2	-
0703	22	0.5	0
0704-0710	400	2.5 ± 0.2	-
0710	22	2.0	-
0710-0717	500	3.0 ± 0.2	-
0717	22	3.0 ± 0.1	0 ± 5
0718-0724	600	2.0 ± 0.2	-
0724	22	4.0 ± 2	0 ± 5
0725-0731	500	1.5 ± 1.0	290
0731	22	3.0 ± 1.0	20 ± 10
0733-0740	500	4.0 ± 0.5	0
0740	22	2.5 ± 1.0	0
0741	50	3.0	-
0742	150	3.0	-
0743	200	2.0	-
0744	300	1.0	-
0745	400	<0.5	-
0746	500	1.0	-
0746-0750	600	2.0 ± 0.1	185
0750	22	1.0 ± 0.5	0
0751	500	2.0	110
0752	400	1.0	270
0753	300	1.0	250
0754	200	2.5 ± 0.5	355
0755-0801	50	1.0 ± 0.1	-
0802	200	2.0	0
0803	300	1.0	240
0804	500	1.0	140
0806-0810	600	2	215
0811	500	2.5	210
0812	400	2.0	245
0813	300	2.0	210
0813	22	1.5	15 ± 5
0815	100	2.0	20
0815-0834	50	2.0 ± 0.5	-
0835	100	2.5	20
0836	200	2.5	20
0837	300	2.0	345
0838	400	1.0	320
0839	500	0.5	245
0840-0847	600	3.0 ± 0.1	240 ± 10
0847	22	1.5	0 ± 20

Time, EDT	Altitude, Feet AGL	Wind Speed, mph	Wind Azimuth Degrees True North
0848	500	2.5	240
0849	400	2.5	240
0850	300	1.0	290
0851	200	1.0	350
0852	100	1.0	20
0853	50	2.0	20
0906-0910	200	0.5 ± 0.1	-
0910	22	1.5 ± 1	90 ± 90

APPENDIX B

Wind Data - September 23, 1973

Time, EDT	Altitude, Feet AGL	Wind Speed, mph	Wind Azimuth Degrees True North
0627	100	3.5 ± 0.5	200
0627	22	2.5 ± 0.5	180
0754	22	4.5 ± 1.0	195
0754	100	f.S.	200
0757	200	f.S.	210
0759	300	f.S.	230
0800	400	f.S.	240
0802	600	f.S.	250
0809-0815	300	4.0 ± 0.2	240
0810	22	2.5	190
0815-0820	100	3.5 ± 0.1	190-220
0821-0825	300	3.0 ± 0.1	240
0825	22	1.5 ± 0.5	180

f.S. = Full Scale

APPENDIX C

Wind Data - September 24, 1973

Time, EDT	Altitude, Feet AGL	Wind Speed mph	Wind Azimuth Degrees True North
0604-0610	100	>6	50
0607	22	5.5 ± 0.5	15
0620	200	~6	10
0627	200	4.5	-
0627	22	4 ± 0.5	30 ± 10
0628-0631	100	4 ± 0.2	-
0633-0636	200	4.5 ± 0.5	35
0637-0642	300	3.0 ± 1	10
0640	22	2 ± 0.5	15 ± 7
0642-0647	400	2.5 ± 2	50
0649-0655	500	2.5 ± 0.2	90
0656-0700	600	2.5 ± 0.2	50
0700-0710	600	2.5 ± 0.2	100
0710-0740	600	2.5 ± 0.5	110 ± 20
0738	22	2 ± 1.0	15 ± 15
0745-0757	600	2 ± 0.5	164
0758-0801	500	3 ± 0.2	120
0801-0804	300	3 ± 0.2	0
0804-0807	400	3 ± 0.2	20
0807-0811	430	3 ± 0.2	20
0812-0815	350	2.5 ± 0.2	36
0816-0827	200	2.3 ± 0.2	30
0844-0847	300	2.5 ± 0.2	30
0858-0928	200	1.5 ± 1.0	86
0928-0940	200	1.5 ± 1.0	-
1000	600	2	110

APPENDIX D

Wind Data - September 25, 1973

Time, EDT	Altitude, Feet AGL	Wind Speed, mph	Wind Azimuth Degrees True North
0625	100	>5	
0629-0632	100	>5	10
0638-0645	600	f.S.	80
0646-0650	500	f.S.	60
0652-0700	200	~7	70
0708	22	2.5	345
0700-0722	600	7	80
0722-0726	400	~6	80
0726-0753	200	4.5	80
0857-0859	100	4.5	-
0800-0805	7	0.5	-
0803	22	0.8	0
0805-0809	100	4	-
0810-0816	200	~5	60
0810	22	1.5	0
0817-0823	400	~5.5	80
0820	22	2 ± 1	15
0823-0828	600	~5.5	86
0826	22	2.5	6
0829-0840	200	5.5	86
0832	22	1.5	6
0842	22	0	330
0842	200	4.5 ± 1	-
0844	200	4.5 ± 1	-
0844	22	1.5 ± 1	30 ± 10
0847	22	2.0 ± 1	30 ± 10
0847	200	4.5 ± 1	-

f.S. = Full Scale

APPENDIX E

Wind Data - September 26, 1973

Time, EDT	Altitude, Feet AGL	Wind Speed, mph	Wind Azimuth Degrees True North
0613-0620	100	~5	95
	22	3 ± 1	80 ± 10
0621-0625	200	~6	140
0631	350	~6	130
0632	400	~8	130
0633	500	~8	120
0634	600	~8	115
0637	600	>8	115
0637	22	4 ± 1	90
0643-0649	100	~5	100
0657	100	~4,5	80
0659	200	~4,5	90
0700	300	~5.5	90
0701	400	~6	110
0702	500	~7	105
0703-0709	600	~8 ± 1	110
0710	500	~8	115
0712	400	~8	115
0713	200	~7	110
0715-0717	100	~3	120
0718	50	~3	120
0718	22	2.5 ± 1	105
0719	100	~4	115
0721	200	~6	100
0722	300	~6	105
0723	400	~6	110
0724	500	~6	105
0725-0731	600	~7	100
0733	500	~7	95
0734	400	~7	95
0733	300	~7	95
0732	200	~6	95
0731	100	~4.5	-
0732-0746	50	~3	-
0742	22	1.0	91
0747-0750	100	~4	-
0750-0754	200	~7	105
0754-0756	300	~6	110
0757-0800	400	~7	110
0802-0804	500	~7	100
0820-0900	20	4 ± 1	-
0900	22	5 ± 2	

APPENDIX F

Wind Data - September 27, 1973

Time, EDT	Altitude Feet AGL	Wind Speed, mph	Wind Azimuth Degrees True North
0637	100	4.5	45
0638	200	4.5	70
0639	300	5.0	95
0640	400	5.5	105
0643	500	5.5	115
0644	600	~7	115
0645-0650	600	~7.5 ± 0.5	130
0651	400	7	110
0654	300	7	100
0655	200	5.5	80
0656	100	4.5	10
0657-0709	50	4 ± 0.2	10 ± 5
0709	100	3	15
0710	200	3	80
0711	300	4	100
0712	400	~4.5	110
0712 (Note 1)	22	3 ± 0.5	355
0713	500	~6	125
0714	600	~7	125
0714-0721	600	~7 ± 0.2	120 ± 10
0722	500	~7	120
0723	400	~7	115
0724	300	~6.5	110
0725	200	~4.5	100
0728	100	~3.5	40
0729-0736	50	~3.5 ± 0.2	0 ± 10
0737	100	~3	10
0739	200	~3	80
0740	300	~4	105
0741	400	~5.5	110
0742	600	~6	125
0742 (Note 2)	22	~2.5	0
0742-0747	600	~6.5	125
0746	500	~7	125
0747	400	~6	120
0748	300	~6	110
0749	200	~4.5	60
0750 (Note 3)	100	~3	0
0751	50	~3	0
0905	200	~3	5
0906	300	~4.5	80
0907	400	~5.5	110
0908	500	~5.5	115
0908 (Note 4)	22	2 ± 1	18 ± 10
0909	600	~6	120

Time, EDT	Altitude Feet AGL	Wind Speed, mph	Wind Azimuth Degrees True North
0913	500	5.5	115
0914	400	5.5	100
0915	300	6	90
0916	200	5	60
0917	100	5	20
0918	50	4.5	10

Note 1. Cloud stratus movement from SSW to NNE, i.e., wind azimuth ~190°.

Note 2. Cloud stratus movement from SSW to NNE, i.e., wind azimuth ~200°.

Note 3. Overhead aircraft reported ceiling to be 2500 feet MSL.

Note 4. Cloud stratus movement from SSW to NNE, i.e., wind azimuth ~190°.

APPENDIX G

Data on Falling Glycerine Particles

Time Following Release (min.)	Fall Distance (Feet)	Particle Diameter (micrometers)	Particle Composition (% Glycerine)
0.0	1.844	50.00	100.00
1.0	48.588	100.22	12.42
2.0	118.915	113.76	8.49
3.0	202.424	121.91	6.90
4.0	295.438	127.77	5.99
5.0	395.978	132.34	5.39
6.0	502.785	136.09	4.96
7.0	614.983	139.27	4.63

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