Operational Dissipation of Supercooled Fog Using Liquid Propane

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ABSTRACT

This paper describes the equipment, the theory, and the results of an operational fog-dissipation system installed at Fairchild AFB, Washington, during the winter of 1969–70. An array of stationary ground dispensers was employed to determine the effectiveness of such a system for providing operational support to aircraft landings and take-offs. Usable clearings followed 25 of 29 seeding operations conducted to bring field conditions above minima. In 17 cases the clearings were conclusively the result of fog seeding. Natural clearing appeared to be at least partially responsible in the eight other cases. Seeding failed to produce usable results in four cases in which the temperature was 31F or higher. In an additional five cases preventive seeding was carried out when initial conditions were above minima. In these cases no attempt was made to evaluate the results due to the uncertainty in knowing the conditions which would have occurred without seeding. A total of 68 aircraft departures and 35 landings were made possible during the project.

1. Introduction

Various airborne techniques have been used successfully to dissipate supercooled fog, the dispensing of crushed dry ice being the most common. Beckwith (1965) has discussed the impact of supercooled fog seeding on airport operations. The airborne techniques have the advantage of flexibility in seeding fog which drifts from any direction and at any speed, because an aircraft is not restricted by the availability of roads, property boundaries and terrain limitations. A ground-based system, on the other hand, is operationally safer than airborne methods and produces visibility improvement when the fog is not supercooled through its entire depth, but is topped by a warm fog layer. The private property restrictions and terrain limitations inherent in ground-based systems were overcome at Fairchild AFB, Washington. Liquid propane was used as the seeding agent in a manner somewhat similar to Serpolay (1965), Hicks (1967) and Gerdel (1968). One of the primary differences from Serpolay's technique was the distance from the runway at which the dispensers were located.

Fairchild AFB is a U. S. Air Force Strategic Air Command base located on a flat, high prairie ~12 mi west of Spokane, Wash. The land around the base is used primarily for farming and grazing so that it is sparsely populated with the exception of a few small towns. A good network of roads surrounds the base, allowing relatively easy positioning and servicing of the propane dispensers (Fig. 1).

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A high-pressure weather system centered southeast of Fairchild AFB is the principal feature of the synoptic weather pattern which causes fog. Clear skies permit strong radiation heat losses which establishes a sharp nocturnal inversion. This inversion, coupled with a moist, southwesterly, low-level flow, causes fog to form. Normally the fog layer is shallow enough to burn off before noon, at least during the first two days of this weather regime. If the pattern persists for a third day or longer, the fog becomes deeper and solar heating is less effective. The fog may then simply lift to low stratus during the afternoon and reform at the surface at night. This condition will last until a strong frontal system moves through the area and dryer air is advected over the base. The supercooled-fog season starts in mid-October and lasts until mid-March, with most of the fog occurring in December and January. For the ten-year period of June 1957 to May 1967, "seedable" conditions—temperature $\leqslant$ 32F, no precipitation greater than very light, and ceiling and visibility less than 200 ft and/or $\frac{1}{2}$ mile—averaged 127 hr per year; 64% of such conditions occurred in December and January.

2. Theory

The dissipation of supercooled fog is based on the physical principle that supercooled water droplets have a higher vapor pressure than ice crystals at the same temperature. If sufficient ice crystals can be introduced into a supercooled fog and diffused throughout a large enough volume, most of the liquid droplets will be removed by the growth and fallout of the ice crystals.

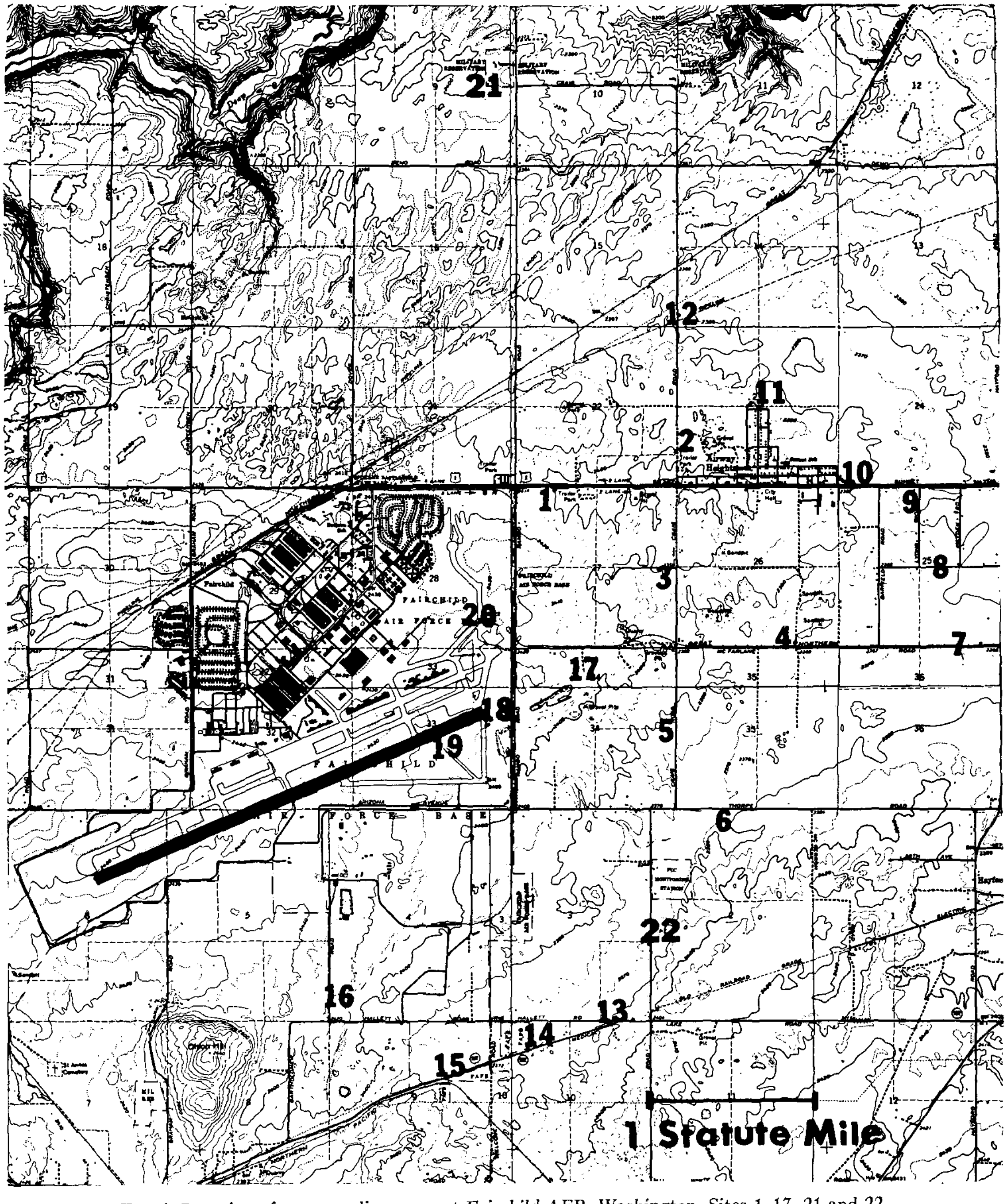

FIG. 1. Location of propane dispensers at Fairchild AFB, Washington. Sites 1–17, 21 and 22 were tower dispensers and sites 18–20 fan dispensers.

As the ice crystals fall out, the visibility correspondingly improves.

a. Ice-crystal generation

The whole process of fog dissipation begins at the point where the ice crystals are generated. The generation of ice crystals is accomplished by releasing liquid propane through an orifice into the foggy air. The vaporizing propane forms a region of extremely cold temperatures. Whenever liquid water droplets are exposed to temperatures < -40F for a sufficient length of time, they will freeze. Likewise at such low temperatures, many additional tiny ice crystals are formed as the cooled air becomes highly supersaturated.

Fig. 2 illustrates the temperature field observed in the flow of liquid propane as it is expelled from a nozzle with a flow rate of $\sim$10 gallons hr^{-1} (0.75 lb min^{-1}). The normal boiling point of liquid propane exposed to a pressure of 1 atm is −44F. However, when liquid propane is broken up into a spray by forcing it through a nozzle, droplet evaporation is nearly instantaneous, and the latent heat of vaporization can reduce the temperature far below the nominal boiling point.

The generation of ice crystals is affected by the speed at which the air passes through the cold temperature region near the nozzle. A minimum residence time is required for the fog droplets to be in contact with the cold temperatures. If the droplet is not in the cold region long enough for it to lose sufficient heat, it will not freeze. If it is in the cold region too long, the dispenser is not efficient. Likewise, there is an optimum residence time for ice crystals to be generated from the ambient water vapor. Although no formal tests were conducted to determine this effect, indications were that the dispensers were not operating at maximum efficiency. That is, more ice crystals would have been generated if the air had been forced through the cold region at higher speeds. On four of the dispensers a high-speed electric fan was mounted to force the ice crystals up into the fog. The fans created speeds >50 mph past the nozzles. In general, the fan dispensers appeared to create many more ice crystals than the tower dispensers which were dependent only upon the wind speed to move the foggy air through the cold region.

b. *Ice crystal diffusion*

Once the ice crystals have been generated by the propane, they must be distributed throughout the fog. Natural diffusion processes play the major role in distributing the crystals. Two types of dispensers were designed to aid the natural diffusion. Because the wind is normally stronger higher above the ground, tower dispensers were chosen to create the ice crystals in this higher wind region. Furthermore, the cold plume created by the propane is heavier than the ambient air and tends to bend downwind. By placing the source of ice crystals higher in the air the plume has a greater opportunity to diffuse before surface features have a chance to scavenge ice crystals. Naturally, the higher the source is placed into the fog the more efficient it becomes. However, equipment limitations become the constraint. First, a practical, inexpensive tower which can be raised and lowered easily to permit servicing of the nozzles limits the height. Second, since it is not economical to build a tower which will permit placement of a 500-gallon propane tank at the top, the propane must be piped up the tower. At temperatures near 32F and pressures near sea level, the theoretical height limit to which the vapor pressure of the propane in the tank will force liquid propane is ~200 ft. However, the practical limit is much less. As the propane works its way up the pipe it experiences lower and lower pressure. Bubbles of gaseous propane begin to form and rise up the tube. Because very little cooling occurs at the nozzle by expansion of gaseous propane, this gas formation reduces the efficiency. Even at a height of 20 ft these bubbles are created and cause the flow to pulsate. This effect is observed as a sputtering at the nozzle. More experimentation is required to determine the optimum height, but 20 ft proved very successful.

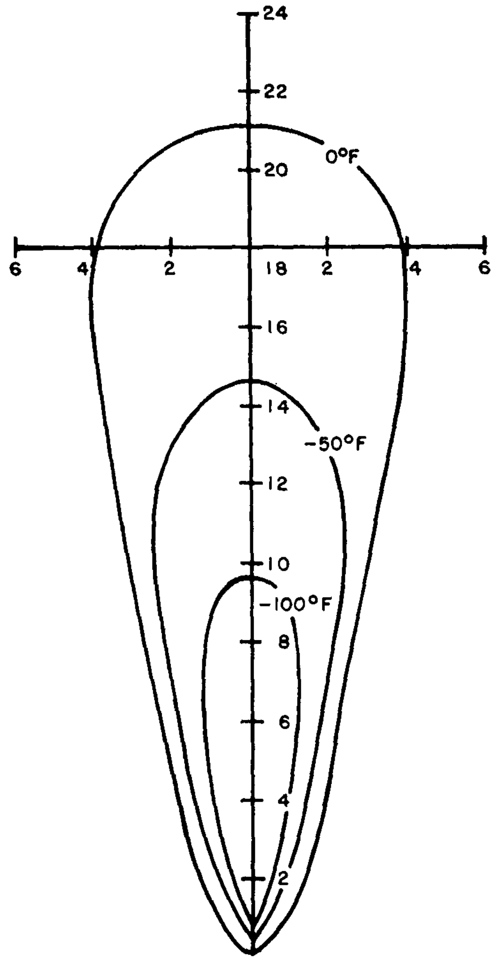

Fig. 2. Temperature distribution of expanding propane. Scale is in inches and flow rate is 10 gallons hr^{-1}.

The tower dispenser was designed to operate in fog with some wind even though slight. In those cases where the wind was calm it was felt that a method for increasing the initial diffusion would be desirable. A 2-ft diameter electric fan was mounted vertically under the dispensing nozzle to force the crystals up into the fog. The nozzles were mounted above the fan rather than below it. It was realized that the fan would create compressional and electrical heating, possibly destroying some of the ice crystals if they were forced to traverse the warm region. This would be most critical when the ambient temperature was near 32F. Slight warming was found to occur, with the temperature immediately above the fan reaching 1F above ambient. At a distance of 18 inches above the fan where the nozzles were located, the temperature rise could no longer be detected.

As the crystals move farther away from the dispensers they diffuse both horizontally and vertically. Measurements of vertical diffusion are difficult to obtain. One thing is clear, however; the ice crystals do diffuse vertically quite well. In many cases the clearing extended entirely through a 1000–1500 ft thick fog layer. While turbulent diffusion is the primary factor, some experts credit the latent heat released due to droplet freezing and subsequent vapor condensation with adding buoyancy to the crystals, thereby enhancing vertical dispersion.

If one considers only the horizontal diffusion for a moment, the tremendous effect wind speed has is quite impressive. Fig. 3 illustrates the effect of a change in wind speed on the plumes downwind of the dispensers. The plume widths are those determined from actual measurements in 3- and 6-kt fog situations. The two most critical factors for ensuring sufficient ice-crystal diffusion are the distance of the dispensers upwind from the target and the spacing between dispensers. Selection of these factors is primarily dependent upon the winds typical at the location.

c. Visibility improvement

The primary improvement in visibility is due to the removal of moisture from the atmosphere as snow.

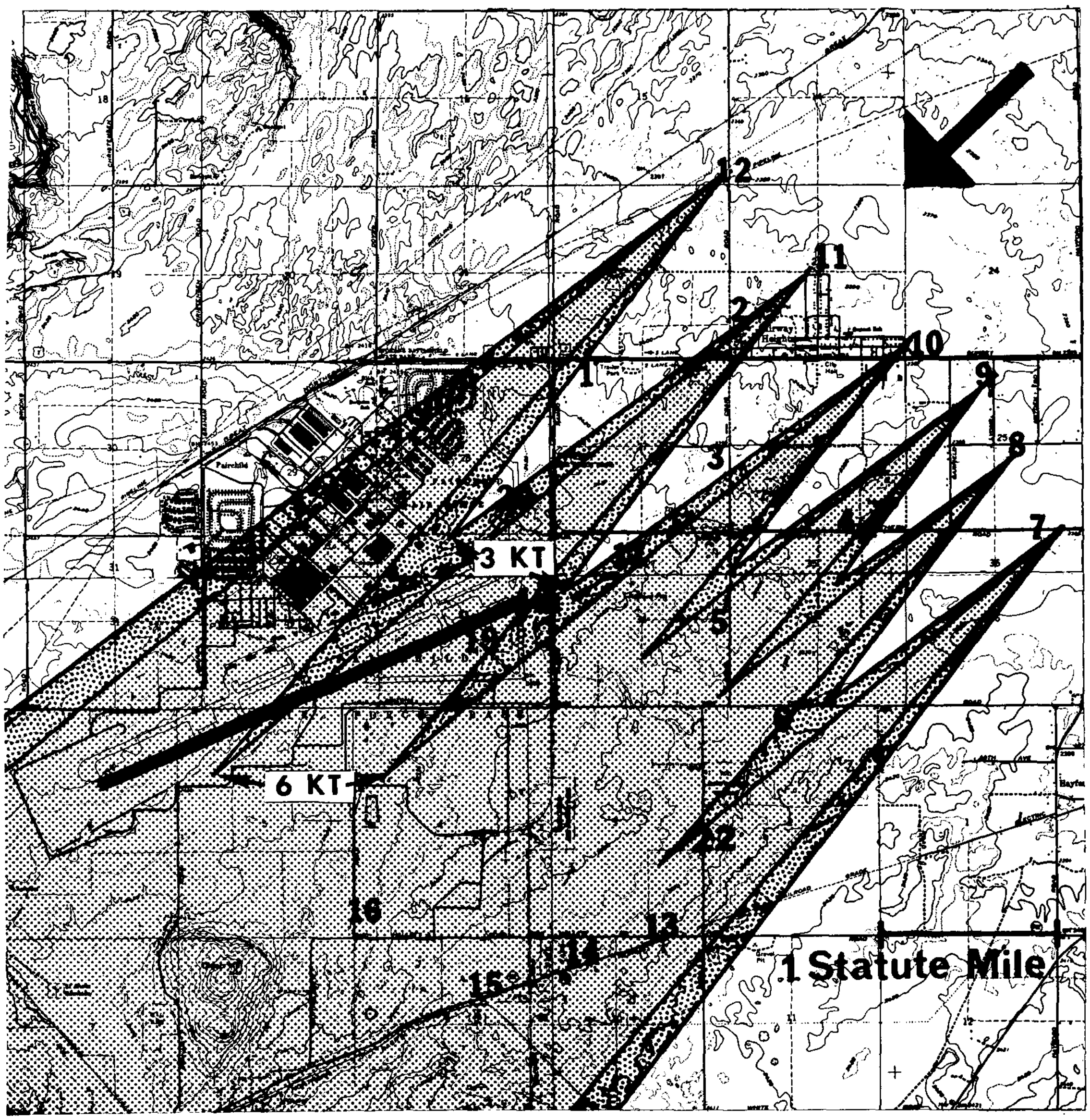

FIG. 3. Horizontal diffusion of ice crystals in 3- and 6-kt winds.

TABLE 1. Visibility as a function of time downwind.

Reaction time (min)	Transmissivity (%)	Runway visual range (ft) (Light setting 5) Day	Night
15	30	1800	3800
30	50	2600	6000
45	70	4100	6000+
60	80	6000+	6000+

The improvement is a gradual one which is dependent upon the diffusion of the ice crystals through the fog, their growth to fallout size, and their subsequent fallout. Normally, the farther downwind from the dispensers, the better will be the visibility. Table 1 gives the average visibility which can be expected as a function of time downwind assuming the initial visibility is on the order of 300 ft. The values were derived empirically from both airborne seeding with dry ice and ground-based seeding with propane, with emphasis on the latter. Many effects can change these values but they should be of some value for planning purposes. Since sufficient time must be allowed for the desired visibility to be attained, average wind speeds must be considered when locating the dispensers upwind.

Separate from the removal process by fallout is an initial visibility enhancement process which Serpolay has used to advantage at Orly Airport in Paris, France. Due to the houses surrounding the airport he was forced to place his dispensers quite close to the runway. The formation and growth of the ice crystals results in a diminution of the number of fog droplets. A small improvement in visibility would be expected due to the change in the number density of the fog particles. However, there is insufficient time for ice crystal fallout to occur prior to the seeded area reaching the runway. At Orly, where quite low landing minima are in effect, this process is sufficient, but at many air bases where the landing minima are 0.5–1 mile the fallout process is mandatory.

3. Equipment

A basic array of 22 propane dispensers was positioned at Fairchild AFB as illustrated in Fig. 1. Climatology indicated that the wind was from the northeast or south with a speed <8 kt during about 70% of the fog occurrences. The dispensers were located between 2000 and 3000 ft apart based on tests the previous year that showed this spacing would allow overlap of the plumes from adjacent dispensers before reaching the end of the runway. Sites were located near roads to allow easy access for turning them on and off and for replenishing the propane.

Dispensers at sites numbered 1–16 and 21–22 were tower dispensers (Fig. 4). These dispensers consisted of a tank of liquid propane, a vertical tower ~20 ft high, and a ½ inch pipe and flexible hose to conduct the liquid propane from the tank to a vaporizing nozzle on top of the tower. Each tank was equipped with a siphon tube to enable liquid rather than gaseous propane to be drawn out. The propane was turned on and off by hand. Propane flow rates could be varied by changing the size of the vaporizing nozzle. The towers could be lowered to facilitate changing or clearing the nozzles.

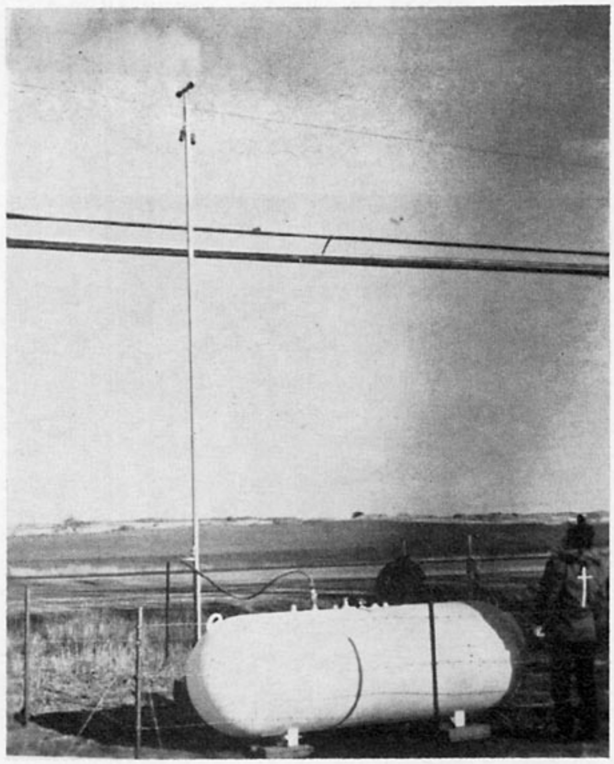

FIG. 4. Collapsible tower dispenser.

The dispensers at sites numbered 17–20 were for use during completely calm wind conditions. One of these units is pictured in Fig. 5. The spray boom was similar

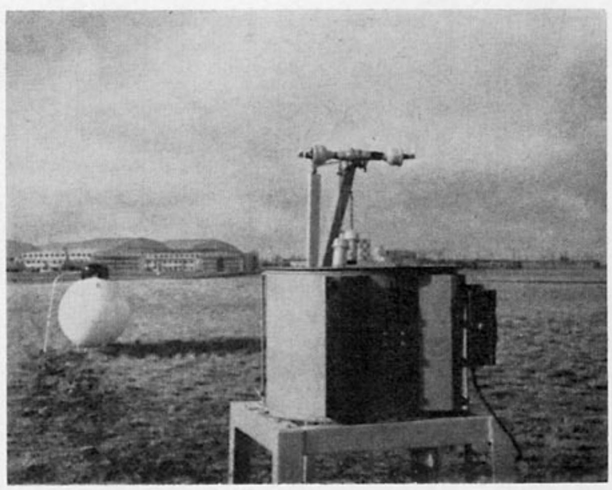

FIG. 5. Fan dispenser.

to that used on the tower dispensers. A 24-inch diameter electric fan was used to blow the ice crystals to a height of 35–50 ft to assist their diffusion into the fog.

Activation of the dispensers required removing the orifice covers, raising the towers, and turning on a valve, a simple operation. Activating all the dispensers needed for a seeding operation required about 45 min, however, because of the time needed to drive safely between dispensers.

Additional instrumentation was added to the available standard airfield instrumentation to measure and record winds, temperature and visibility in the fog.

4. Procedure

Four personnel were engaged in the seeding operations under normal circumstances: a project director, two dispenser operators, and a runway observer. An equipment maintenance technician and a photographer were also assigned to the project. No special training was required beyond a briefing on the objectives of the project and procedures to be followed.

The two dispenser operators were deployed about 75 min before scheduled aircraft operations if cold fog was occurring or forecast to occur. The dispensers to be used were selected primarily on the basis of the winds measured by a sensitive anemometer located on the top of the control tower. Radio communications with the deployed personnel allowed changes to be made if the winds changed. The dispensers were run continuously until no additional aircraft operations were scheduled or until natural clearing occurred.

The dispenser operators made weather observations in the area between the dispensers and the end of the runway and in the fog around the cleared area to verify that the clearing resulted from seeding, not natural causes. An observer at the approach end of the runway monitored the runway visibility to ensure that full use could be made of the clearing in the event it did not affect the transmissometer. The photographer was located with the runway observer to obtain photo documentation of the visibility increases.

5. Test results

A total of 34 operational seedings were conducted. Observations were made to determine the effects of various factors on the success of ground-based fog seeding.

a. *Effect of wind*

No problems were encountered in producing a clearing over the field if the termperature was 30F or less, the winds were from a direction protected by dispensers, and the most distant dispensers in that direction were used. When winds were from a direction near one end of the dispenser array, results were marginal, although intermittently visibilities would improve to above minima. The runway observer provided valuable information during these periods, since the clearings could improve the approach zone and the end of the runway but not reach the transmissometer.

Early in the season the close-in tower dispensers (1–6) were used when the official wind observation was 2 kt or less. It was found that the fog generally drifted faster than the indicated 2 kt, however, and the snow produced by the seeding would fall onto the airfield and any aircraft awaiting takeoff. However, the snow would fall out before reaching the runway if the more distant dispensers were used. For this reason dispensers 1–6 were rarely employed during the remainder of the season.

Three wind instruments were available during the test program. A standard and a sensitive wind set were both located at a height of 13 ft above the ground, while a second sensitive instrument was placed at a height of 120 ft on the control tower. A comparison was made among the different types of wind vanes at various locations and heights to determine which one was most accurate for determining the direction of drift of the fog. The observed drift was in good agreement in all cases with the 120-ft wind vane. All of the large deviations between fog drift and the surface wind observations occurred with cases where the wind was 3 kt or less.

Since the speed of the wind is equally important for forecasting the time for the clearing to reach the field, a comparison was also made of these measurements. The standard runway anemometer was found to be considerably less sensitive at lighter wind speeds, recording calm winds 31% of the time compared to 8% for the sensitive anemometer at the same height. The sensitive anemometer recorded calm only 2% of the time at 120 ft. This apparent infrequency of dead calm conditions was verified by observations of the fog drift.

A comparison was made of the speed of drift of the seeded fog and the speed as measured by the two types of surface anemometers. The drift of the clearings ranged from slightly less than the speed indicated by the anemometers to as much as twice as fast. The anemometer at 120 ft generally indicated stronger winds than the anemometers located near the ground and appeared to represent more closely the actual drift of the fog.

b. *Effect of temperature*

Six seeding operations were conducted at a temperature of 31F or slightly higher. Clearing was achieved twice. Ice crystals were produced in two other cases but no clearing was observed. No effects of seeding could be found in the remaining two cases. In the two successful seeding efforts the fog was less than 150 ft deep.

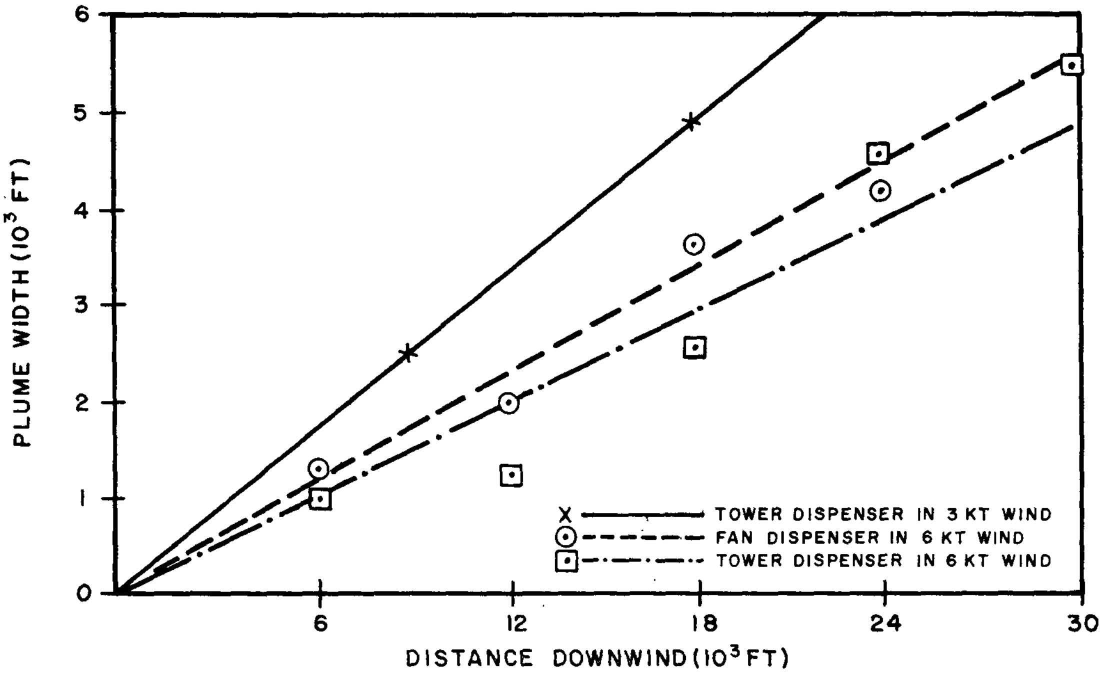

FIG. 6. Plume width vs distance downwind for the two types of dispensers.

One of the two successful operations took place on 26 February 1970. Seeding started at 0555 PST when the temperature was 29F and rising. After 90 min of seeding the temperature was between 30F and 31F and field conditions had improved to well above minima. The dispensers were shut off to see if in fact the clearing created was due to the seeding; within 10 min the visibility dropped to below minima. Seeding was started again, and again the visibility improved. It began to deteriorate once more, however, when the temperature reached 32F, so seeding was discontinued.

c. Effect of the vertical fan

On 19 January a supplementary test was conducted in which a fan dispenser and a tower dispenser were operated simultaneously and the plumes were tracked downwind to compare their widths. The wind was 6 kt and the temperature at 60 ft was 1F colder than at the surface, about the same as in most of the seeding operations conducted. The results are shown in Fig. 6. The difference in width was only 500 ft at 3 mi downwind. It was clear that lateral diffusion was not significantly aided by use of the fan.

d. Representativeness of runway visibility observations

A weather observer was stationed at the threshold of the active runway from about one hour prior to the start of seeding until seeding was stopped. At 10-min intervals he recorded observations of field conditions, principally of visibility along the runway. Observations of runway visibility were compared to the transmissometer-derived RVR to determine the representativeness of the instrument during fog-dispersal operations.

The transmissometer recorded above-minimum conditions 34.4 hr as a result of seeding. On 24 occasions, for a total of 6.6 hr, the runway observer noted runway visibility above approach minima while the transmissometer indicated the visibility was below minima. The duration of these differences was greater than 20 min in six instances, for a total of 4 hr. On 12 occasions, for a total of 2.4 hr, the runway observer recorded runway visibility below minima while the transmissometer indicated runway visibility above minima. The duration of these differences was greater than 20 min only twice, for 24 and 28 min, respectively. These differences occurred most frequently when the wind was from a direction near the end of the dispenser array, with the runway on the edge of the clearing.

e. Effect of propane dispensing rate

A seeding rate of 25 gallons per hour (gph) from each dispenser was used at the beginning of the season. The rate was reduced to 15 gph on 12 December and to 10 gph on 2 January. There was no noticeable reduction in clearing action.

f. Flammability of plume

Propane is flammable when mixed with air in concentrations between 2.4 and 9.5%, but previous computations indicated these proportions exist only in the region 4–10 ft from the dispensing orifice. Tests were conducted in a 2-kt wind to determine the extent of the

FIG. 7. Ignition region of burning propane plume.

fire hazard involved in vaporizing liquid propane from the dispensers. A flow rate of 10 gph was used. It was found that to ignite the plume of propane it was necessary to bring the ignition source within 4 ft of the dispensing orifice, to a point actually within the visible plume of vaporizing propane. Fig. 7 shows a burning plume of propane being emitted from one of the orifices on a dispenser head while the plume from the second orifice, some 18 inches away, remains unignited. A wind of 4 kt or more would blow the flame out. The plumes from a fan dispenser could not be ignited when the fan was operating. If the plume was lighted first and the fan then turned on, the flame was immediately extinguished.

g. Snowfall

Up to $\frac{1}{16}$ inch of snow per hour is produced in the area from 0.5–3 mi downwind of the dispensers. Fig. 8 shows the fallout from a typical seeding operation. The shape and extent of the area in which snow is deposited depend on the wind speed. Dense, deep fog produces slightly heavier fallout than thin fogs.

FIG. 8. Typical snowfall at a distance of 5 mi from the dispensers due to seeding on 25 November 1969 for 5 hr.

h. Propane odor

Propane is a colorless, odorless, hydrocarbon which is harmless to plant and animal life. The quantities used in seeding are so small, 0.75 lb min^{-1} from each dispenser, that there is no accumulation leading to a pollution problem. Though propane itself has no smell, it is purposely stenched as a safety measure. When used for cooking and heating, the smell calls attention to leaks that could lead to dangerous concentrations indoors. Initially, unstenched propane was used at Fairchild AFB, but midway through the season it became necessary to use the stenched type due to lack of a reliable supply of unstenched propane. The odor of stenched propane was detectable for a distance of approximately $\frac{1}{4}$ mi downwind of a dispenser. This produced a nuisance but no hazard.

i. Example of a successful seeding operation

Figs. 9–11 illustrate the results that can be achieved in cold fog at a suitable temperature. They are from a seeding operation that began at 1200 PST on 2 December 1969 and ended at 0230 PST on 3 December 1969. The seeding operation was conducted to support tactical flying activities associated with an Operational Readiness Inspection of the 92nd Strategic Aerospace Wing. Dispensers 7–12 were used at the start of seeding. Field conditions all through the morning were well below approach minima, as illustrated by Fig. 9, a picture taken from the control tower at 1220 before the effects of seeding had reached the field. At this

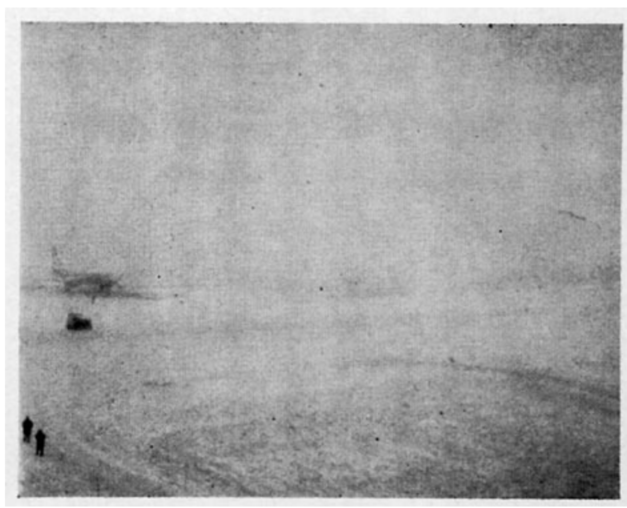

FIG. 9. Visibility conditions at Fairchild AFB prior to seeding on 2 December 1969. The photograph was taken looking east from the control tower at 1220 PST before the effects of seeding which had begun at 1200 reached the field. The prevailing visibility at this time was $\frac{1}{8}$ mile.

time the local weather observation was ceiling 200 ft, sky obscured, prevailing visibility $\frac{1}{8}$ mile, RVR <1000 ft, wind from 040 deg at 4 kt, and temperature 25F. The RVR went above 2400 ft at 1242 PST and by 1305, when the picture in Fig. 10 was taken, it was 5500 ft. At 1328, as the first B-52 was taking off, visibility had improved to the point that a hill ~2 mi away could be seen. By 1405 (Fig. 11) the entire 1000-ft depth of fog had dissipated, allowing the sun to shine through.

Field conditions were maintained at or above minima throughout the entire operation, except for brief instances when the wind shifted to a northerly direction (dispenser no. 21 had not yet been installed).

The dispenser operators reported that the visibility remained at $\frac{1}{8}$–$\frac{1}{4}$ mi at the dispenser sites and to sides of the clearing throughout the entire period. All of the 26 aircraft engaged in the exercise made on-time take-offs and all of the 20 scheduled to return to Fairchild landed successfully.

FIG. 11. B-52 taking off at 1407 PST. By this time the clearing had developed through the entire 1000-ft depth of fog permitting the sun to shine through.

j. Test summary

During the 29 operational seedings conducted to bring field conditions above minima, 25 usable clearings occurred. In 17 cases the clearing was entirely the result of seeding, and in eight cases natural clearing also appeared to be occurring simultaneously. In five of the 17 tests in which the clearing was conclusively due to seeding the visibility was intermittently above and below minima due to winds intermittently shifting to unprotected directions. On five occasions seeding was initiated while the visibility was above minima and, except for brief periods, the visibility stayed above minima. Since it could not be determined if the visibility would have deteriorated naturally, these cases were not included in the analysis. In four cases seeding did not produce usable results. In each of these cases the temperature was at or slightly above 31F.

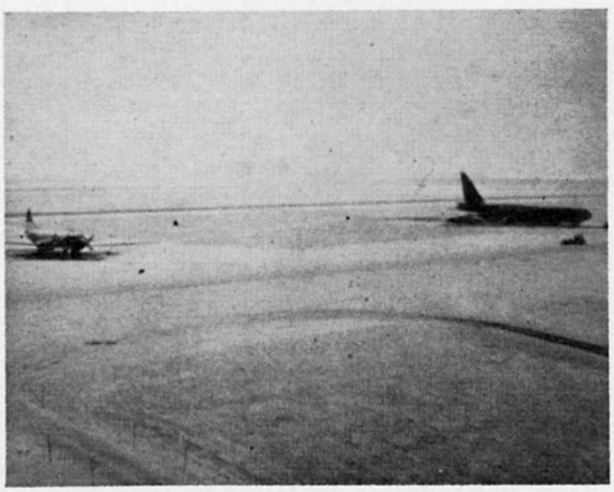

FIG. 10. Visibility conditions at 1305 PST after seeding effects had reached the field. The first aircraft took off at 1328.

k. Operational impact

Table 2 summarizes aircraft movements made possible or expedited by the seeding operation.

The 92nd Strategic Aerospace Wing at Fairchild AFB prepared a study that indicated a net savings in operating costs of $232,800 for project Cold Wand over the entire season. The cost of equipment and supplies for the entire season was $14,000.

6. Design improvements

Now that the ground-based system has been proven effective for operational use, the final step in making it as responsive as possible is to engineer the system so that the dispensers can be controlled by a single operator in a central location. It is only a matter of acquiring sufficient telephone circuits to control the dispensers with relays and solenoid valves and to monitor the dispenser operation. Power can be supplied to operate the valves from nearby power sources or with storage batteries if the sites are remote. Fabre (1969) discusses the installation of such a system at Orly Airport.

Some of the initial sites at Fairchild were found to be too close to the runway and these will be removed. Additional dispensers need to be added in other directions around the base to permit seeding of a higher

TABLE 2. Aircraft operations.

Aircraft type	Take-offs	Landings
B-52	26	11
KC-135	32	19
C-47	5	0
Other	5	5
Total	68	35

percentage of the fog. With the addition of four more dispensers, the effectiveness of the system could be increased to 90–95%.

Other bases are now being considered for installation of a propane system. The most challenging is Hahn AB in Germany. A propane system is planned for installation there in the winter of 1970–71. Hahn AB has about 175 hours of supercooled fog compared to 127 hours at Fairchild AFB. The winds normally accompanying the fogs range from 8 to 15 kt. Because of these high winds and also because of the requirement for an operating visibility of 1 mi, two rows of dispensers are being installed, one at 5 n mi for use with winds <7 kt and the other at 10 n mi for use with stronger winds. In addition to high winds, Hahn AB is situated in an area of rugged terrain which causes some uncertainty in determining the flow patterns in the fog. If the operation planned at Hahn AB is successful, there is reason to believe that a ground-based propane system could be designed for practically any base or airport experiencing supercooled fog.

7. Freezing-drizzle seeding

During the fog-seeding project at Fairchild AFB one of the alert criteria for the seeding team was the occurrence of freezing drizzle. It was suggested (personal communication from R. D. Fletcher, Headquarters Air Weather Service) that a test be run to determine whether propane seeding could cause freezing of the supercooled drizzle droplets before they reached the ground and produced glazed conditions. One case of freezing drizzle occurred on 19 January 1970. The temperature was 26F and the wind was about 8 kt from the east-northeast. The drizzle lasted from about 0730 to 0845. During this time dispensers 1, 3 and 4 were activated and the effects observed downwind along roads to the south and west (see Fig. 12). Four separate traverses were made through the effects downwind of the dispensers.

A small piece of blue felt was used to detect the frozen drizzle, and the windshield of the observing truck was used to observe the unfrozen drizzle. Within the plumes shown in Fig. 12 the drizzle was completely frozen with no splashing on the windshield, but small spherical ice particles were collected on the felt. The ice particles exhibited a spherical shell around a liquid center. Outside the plumes the drizzle was unaffected by the seeding.

Further testing of this very interesting phenomenon is warranted. Should seeding of freezing drizzle be found effective in general, changing the drizzle droplets to ice particles may under some circumstances be a practical method for preventing glazing conditions on runways and roads.

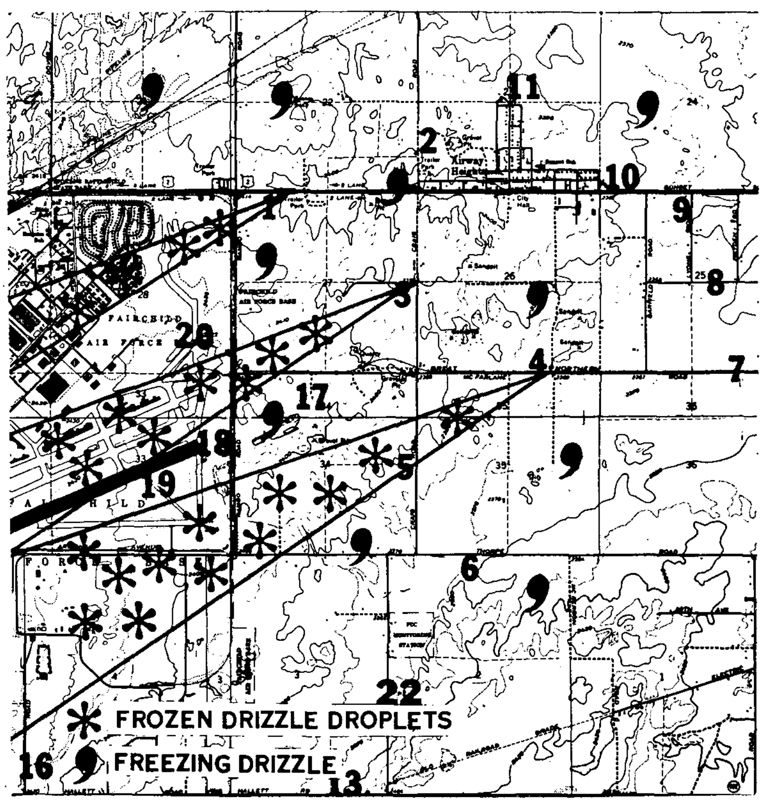

FIG. 12. Diagram of seeding effects from dispensers 1, 3 and 4 during a case of freezing drizzle on 19 January 1970.

8. Conclusions

Ground-based dissipation of supercooled fog using stationary propane dispensers proved highly effective for supporting landing and take-off operations at Fairchild AFB.

Visibility improvements can be produced reliably in fog with a surface temperature equal to or less than 30F. Results are marginal at 31F, although if the fog is relatively shallow prospects of achieving useful results are good.

The diffusion of the seeding materials (ice crystals) through the fog is done efficiently by natural small-scale turbulence. The wind, when measured by a sensitive anemometer, was seldom truly calm, suggesting that a fair degree of small-scale turbulence commonly exists. The movement of the seeded fog is normally faster than that indicated by surface wind measurements, indicating stronger winds above the surface. The sensitive wind sensor mounted atop the control tower provides more reliable information on which to make estimates of the drift of the seeded fog. The difference in its measurement, when compared with the standard surface measurement, is principally in speed rather than direction.

Measurements of runway visibility by an observer stationed adjacent to the runway do vary significantly on occasions from those derived from transmissometer readings. This was usually observed, as expected, when the runway was near the edge of the cleared area.

Fans are not required to distribute the ice crystals when the wind speed is greater than zero. Four fans were available at the close-in dispensers for use in calm wind cases, but calm and very light winds were so rare that it was not possible to determine if they were actually needed.

A liquid-propane dispensing rate of 10 gallons hr^{-1} from each dispenser was adequate. Lower dispensing rates may suffice but were not tested.

Stenched propane is a nuisance, but not a major one, in the lightly populated area surrounding Fairchild AFB.

Previous computations showing that the plume of propane could be ignited only from 4–10 ft from the emitting orifice were corroborated. The use of propane in this manner does not constitute a hazard to safety so long as reasonable precautions are observed.

Some light snowfall will result from fog-dispersal operations. This is identical to natural snowfall and accumulates at a rate usually less than $\frac{1}{16}$ inch hr^{-1}.

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