RECENT ADVANCES IN WEATHER MODIFICATION

FOR IMPROVEMENT OF AIRPORT OPERATIONS

by

J. R. Hicks

Research Meteorologist

U. S. Army Cold Regions Research and Engineering Laboratory
Hanover, New Hampshire

Abstract

The U. S. Army Cold Regions Research and Engineering Laboratory has succeeded in dissipating supercooled clouds over the Greenland Ice Cap near Camp Century by conventional methods, i.e., dry ice distributed over the cloud top by aircraft. The laboratory is now investigating several ground-based systems: tethered balloons, mortars, rockets and other devices to introduce seeding materials into clouds or fog. Dry ice is the principle reagent being used, but other chemicals: metaldehyde, propane and phloroglucinol are being investigated.

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I. Introduction

In the past fifteen years more than twenty papers on Weather Modification have been presented to this and the Western Snow Conferences. Most of these have described efforts to increase precipitation in the western parts of the U. S. and Canada. Other papers have described hail and lightning suppression experiments. In 1958, Dr. Gerdel spoke before the Eastern Snow Conference about the problem of visibility in Cold Regions. He described some of the problems of surface and air transportation which is greatly influenced by fog and other types of the so-called "Whiteout" conditions. He stated that clearance of fog and low stratus might be possible, and he suggested some methods which might work. Since then, USA CRREL has determined that the supercooled fog and stratus which occurs over the Greenland Ice Cap can be dispersed by seeding. This was done by aircraft; however, when aircraft can fly to do the seeding, the need for improved visibility does not really exist. Therefore, our latest efforts have been directed primarily toward developing a ground based system for introducing the seeding materials into the fog or cloud.

II. Résumé of Previous Studies by USA CRREL

A number of systems have been studied by USA CRREL. Some have been discarded as unfeasible while others have shown enough promise to warrant further study:

A. Silver Iodide Generator. In 1957 a series of seeding experiments using ground-based silver iodide generators were performed. Each generator consisted of a propane flame into which a cotton cord, impregnated with a silver iodide solution, was fed.

Results of these tests were inconclusive although several light snow showers were observed to form downwind from the seeding site.

The idea of ground-based generators at first appears good: an economical, continuous stream of crystals can be injected into the air flow. However, two factors combine to preclude the use of this system: 1) Silver iodide has not proved to be a very reliable nucleating agent under field conditions. This is especially true at the warmer temperatures (-5° C to 0° C), and 2) The silver iodide crystals which are released at the surface cannot penetrate the shallow inversion layer which is usually present over the ice cap. Therefore, a more positive system for injecting the seeding materials into the clouds is needed.

B. Mortars. A mortar-type seeding device was tested in Greenland in 1958. Silver iodide "Warheads" were used but with little apparent success.

Positive injection of the seeding material into the fog was obtained, but further tests were discontinued largely because of the apparent ineffectiveness of the system. The failure may be due to the destruction of the silver iodide by the high flash temperature of the exploding warhead.

The idea of seeding with mortar-type vehicles has not been entirely discarded, but no further experiments are scheduled at this time. When better seeding materials and equipment become available, more tests will be made.

C. Balloons and Fixed Supports For Dispersing Seeding Materials.

1. Free Balloons. Several tests were made in the Thule, Greenland, area in which bags of dry ice were suspended from helium-filled balloons and allowed to rise freely into the clouds. Dispersion of the seeding material was accomplished by detonating blasting caps imbedded in the dry ice. The proper height for release of the material was obtained by using balloons of known rise rates and fuzes of known burning rates (see Figure 1).

During these tests several breaks in the fog were observed but it could not be determined whether or not they were caused by the seeding.

This system has several drawbacks: it is cumbersome; requires several men to keep it going; cannot be used in high-wind conditions; and is somewhat hazardous due to the explosives used. Consequently, additional experiments using this system have not been scheduled.

2. Tethered Balloons. A Seyfang 1004 blimp-balloon, capable of lifting about 30 pounds at sea level, was used to lift small plastic fruit baskets each of which contained a 12-oz. cake of dry ice. These baskets were placed along the tether at 50-foot intervals, enough baskets being used to penetrate the entire cloud layer (see Figure 2).

This system was effective on low stratus where the results could be seen from the immediate vicinity of the test site, but the results of succeeding tests in heavy ground fog could not be determined. It is probable that clearing occurred several miles downwind, beyond the safe limit of travel by surface vehicles in whiteout conditions.

The disadvantages of this system seem to outweigh the advantages. It's use is limited to periods of light winds; it requires considerable hangar space; replacement of the dry ice containers on the tether is difficult; can be used only with dry ice or perhaps propane.

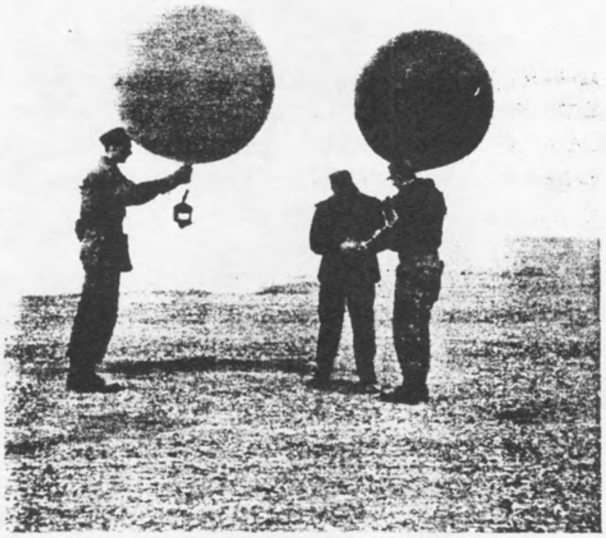

Figure 1. Cloud seeding with free balloons.

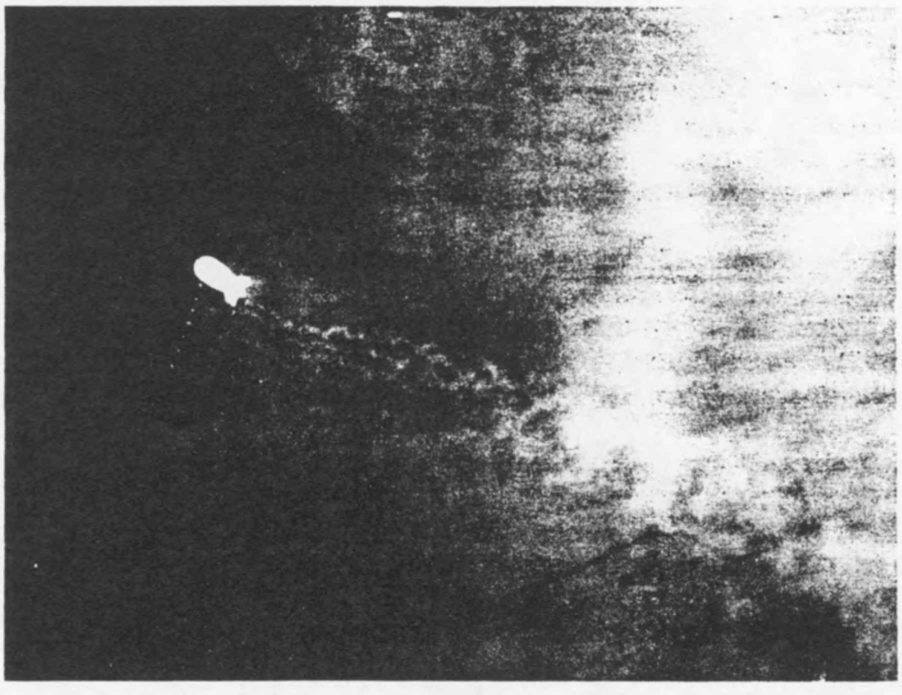

Figure 2. Seeding with tethered blimp-balloon.

3. Pole Supports for Dry Ice. Twelve-ounce cakes of dry ice were impaled on the ends of 12-foot bamboo poles which were stuck in the snow in a line normal to the wind. The poles were spaced about 100 feet apart.

This system was used during periods of ground fog. Nucleation was observed and heavy plumes emanated from each piece of dry ice. These plumes coalesced downwind about 250', but no further reaction was noted for distances up to about three miles. Since clearing time for this type of seeding is probably 30-45 minutes, it is possible that visibility improved further downwind -- beyond the range of safe surface travel using the oversnow vehicles available at the U. S. Army's test site at Camp Century, Greenland.

D. Aircraft. Crushed dry ice, ranging in size from about 0.5 mm to 15 mm was distributed by Army aircraft about 50 feet above the tops of several supercooled stratus decks over N. W. Greenland. Amounts of dry ice varying from 1 lb to 5 lbs per mile were used. Results of these seedings were generally excellent. Figure 3 shows two views of one clearing which resulted from seeding with dry ice carried aloft by aircraft.

Discussion

This system is by far the most effective one for dissipating supercooled clouds; but it is expensive and, in general, when aircraft can fly, the need for increasing the visibility does not usually exist.

III. Systems Under Investigation and/or In Use

Currently, there are several systems being investigated, and at least two methods are considered operational even though they have not been used enough to establish their reliability.

A. Rockets. Two types of rockets are currently being tested and evaluated by this laboratory: a solid fuel (pyrotechnic) type and a CO_2-propelled model (see Figure 4).

1. Solid Fuel Type

a. Description. This rocket is 29.5 inches long, 2.2 inches in diameter and weighs 4.35 lbs including a one-pound payload. Four ounces of solid fuel propels it to a height of about 2300 feet above the launch elevation where a small powder charge explodes into the base of the cargo compartment, forcing off the plastic nose cones and then the seeding materials.

b. Discussion. These are small easily handled units needing no complex launching systems. They can be loaded with some of the inert seeding materials and stored ready for use at a moments notice.

Figure 3a. Area cleared by dry-ice seeding from aircraft (view from above).

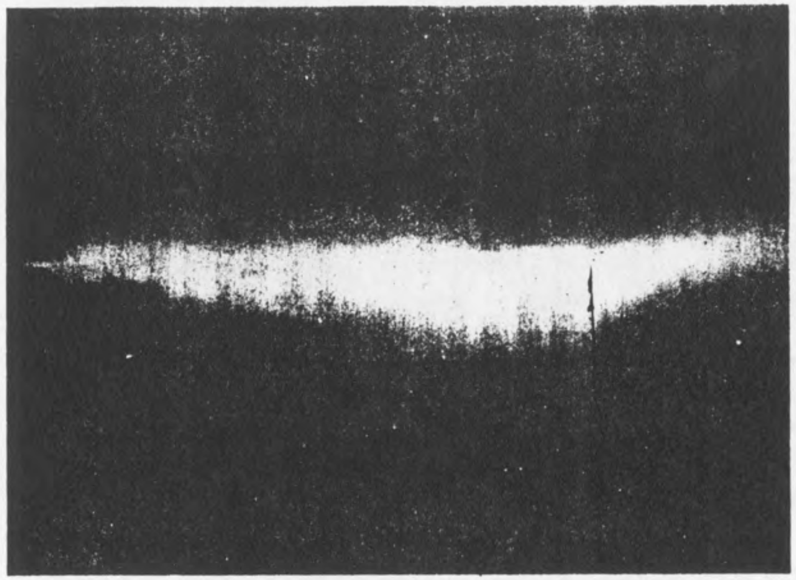

Figure 3b. Area cleared by dry-ice seeding from aircraft (view from below).

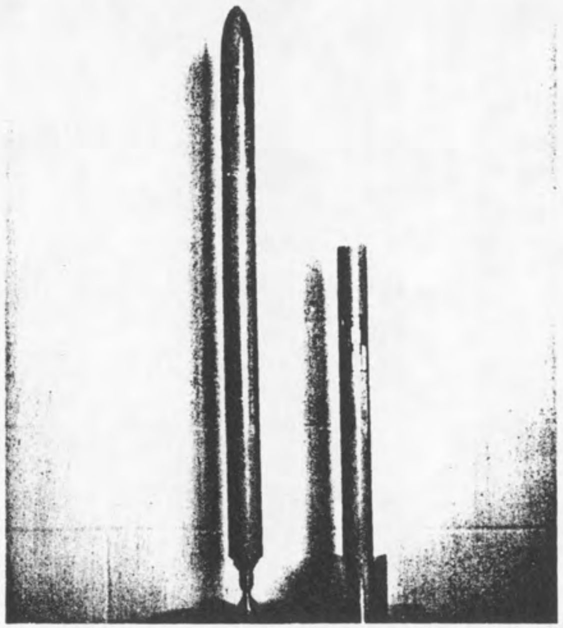

Figure 4. Cloud seeding rockets: CO_2-propelled on left, solid fuel type on right.

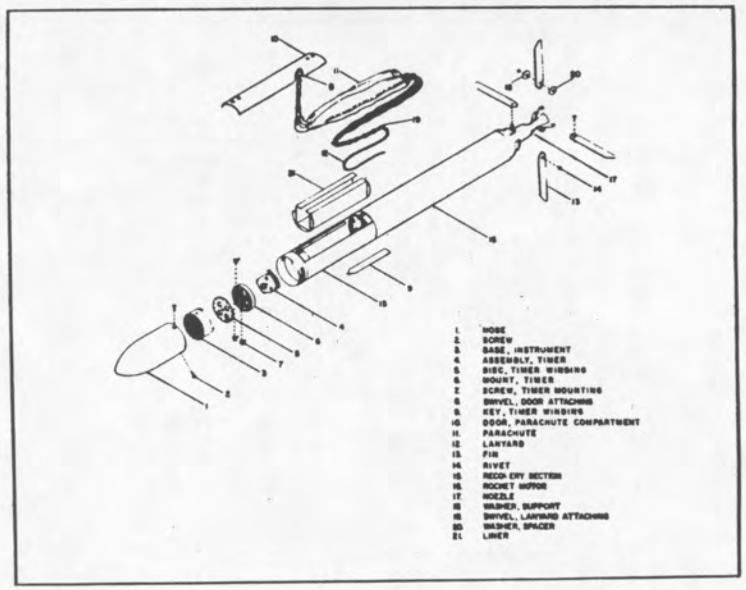

Figure 5. "CRICKET" rocket: exploded view.

However, these units have several disadvantages: 1) they are expensive, costing about $165 each in lots of 50; 2) they are not reusable; 3) they are hazardous -- a 2.5-lb rocket body and nose cone fall freely to earth after each shot and 4) they must be stored in an approved explosive storage area.

Some of these rockets have been procured and will be tested this summer.

2. CO_2-Propelled Rockets

a. Description of System. A Texaco Experiment Incorporated Model III CRICKET (Cold Rocket Instrument Carrying Kit) was modified to provide payload compartments of two sizes: 2.5" x 7.0" and 2.5" x 13.0". The shorter compartment was simply a standard parachute section, without parachute, and the longer compartment was a custom-built section having a door opening the full length, and covering one half (180°) of the cylinder.

The rocket motor (liquid CO_2 and acetone container) is the same for both configurations: measuring 2.5" x 24.5". Performance is varied by using different quantities of acetone and CO_2 which are injected into the rocket just prior to launching.

The cargo is discharged by means of a mechanical timer which releases the cargo door, allowing the seeding material to fall out.

Recovery is accomplished by a 4-foot parachute which is released at, or near, apogee by another mechanical timer.

Figure 5 is an exploded view of the basic rocket, and Figure 6 is a photograph of the modified rocket which uses the larger compartment.

A special launcher is required for these rockets. It consists of a base into which two 10-lb cylinders of CO_2 are mounted, a 10-ft launch tube, and the valves and gages needed to charge the rockets and to eject them from the launch tube.

A complete unit, consisting of a launcher, several large, externally-mounted, cylinders of CO_2, storage rack for 25 rockets and a dry ice maker -- all mounted on a 1-ton sled is shown in Figure 7.

b. Discussion. Flight tests so far have been conducted primarily to determine the flight characteristics of the rockets under various payload, launch pressure and propellant-charge combinations. Only a few flights have been made during actual "Whiteout" conditions, but these brought no significant results since the whiteouts were not the fog or low level stratus types which the system is designed to disperse. Further tests are to be conducted in Greenland this summer.

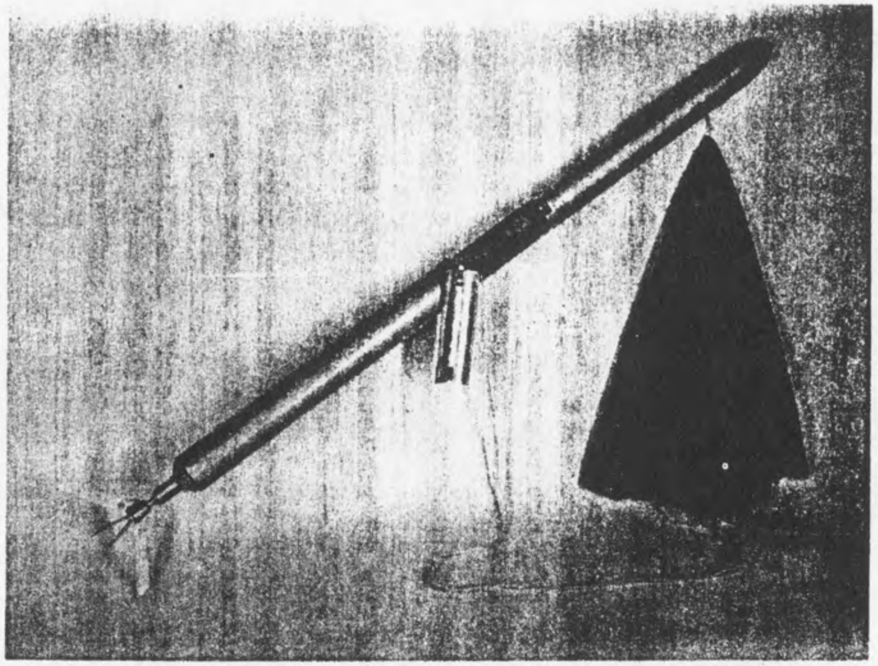

Figure 6. CRICKET rocket equipped with long cargo compartment.

Figure 7. Complete fog dispersing unit mounted on a 1-ton sled.

Figure 8. Vertical fan

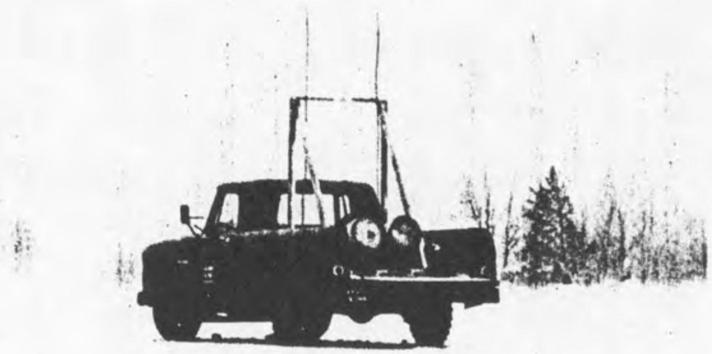

Figure 9. Propane seeding rig

The system has several advantages. It is: 1) economical -- est. cost $3.00/shot; 2) non-flammable; 3) adaptable to almost any seeding material; 4) adaptable to various cloud height conditions, and 5) re-usable.

There are, however, several disadvantages to the system: 1) it requires several men to operate; 2) it constitutes a hazard around power lines and populated areas; 3) recovery of the rockets is sometimes difficult, especially during periods of high winds; and 4) the rockets are somewhat fragile and tend to become damaged quite easily.

B. Vertical Fan

1. Description of the system. This equipment consists of a 14-foot propellor-like blade mounted horizontally on a vertical column about seven feet above the bed of a small trailer. An automobile motor mounted on the trailer drives the fan which blows air vertically upward to a maximum height of about 1700 feet, depending upon the wind condition and the stability of the air layer (see Figure 8).

Seeding materials such as silver-iodide crystals from smoke generators, phloroglucinol, propane or CO_2 can be released near the fan and blown into the fog or low stratus clouds.

2. Discussion. This system has several good features: 1) positive injection of seeding materials into the fog is assured; 2) it is portable, i.e., it can be towed to the best locations near the airport; and 3) initial cost is low, and it is economical to maintain and operate.

On the other hand, it is somewhat hazardous due to the rotating blades; and the area of operation is somewhat restricted.

No seeding runs have been made but several tests have been conducted to determine how high the air can be lifted above the surface. Maximum heights ranged from 400 feet in windy conditions to 1700 feet in calm air having unstable equilibrium.

C. Propane Systems. At one atmosphere of pressure, liquid propane boils at -42.1°C which is below the spontaneous freezing temperature of most supercooled water droplets. It can, therefore, be used to induce freezing of the water droplets in this type of fog or cloud.

1. USA CRREL Experiments

a. Description. The system being tested at the Lebanon Regional Airport, N. H., consists of two 100-lb propane tanks mounted vertically (upside down) on the rear of a pick-up truck. A 12-foot length of 3/8-inch copper tube is attached vertically to each tank.

The end of the tube is bent 90° and several 1/16" holes are located near the end of each tube. During seeding operations the tank valve is opened enough to allow the propane to discharge at about 7 lb/min from one tank, or 5 lb/min from each tank when more than one is used. The truck is driven back and forth so that the vapor is not in danger of being ignited by the truck exhaust, or the operating personnel of being exposed to the fumes.

Figure 9. Shows Rig

Another test installation is located in back of the main USA CRREL building in Hanover, N. H. It consists of a fixed cylinder of propane and a tube having only one 1/16" outlet. When fully opened the rate of discharge of liquid propane is about 2.5 lb/min.

b. Results. In four trials, three were successful in causing the supercooled droplets to freeze and precipitate. In each case dramatic changes occurred: everything in the seeded area became covered with a rime-like snow; halos formed and blue sky appeared in the seeded area. A well-defined line of snow was observed on the ground.

The one failure was attributed to seeding below the bottom of the cloud. A low stratus with a base of 75-100 feet was present over the airport. Propane seeding was done at 12 feet above the ground. Since nothing happened, it appears that the propane must be placed directly in the fog for any modification to occur.

2. Tests at Orly Field, Paris, France. A more sophisticated propane system has been used at Orly Field. It consists of 50 propane stations located to the south, east and north of the airfield. When fog is to be cleared, three or four of the stations (selection depends upon the wind direction) are activated by remote electrical control. Visibility at the airport is monitored by several transmissometers.

Results were generally good as shown in the following exerpt from one of the reports[1].

> "On 19, 20 and 21 January 1964, Orly Airfield was covered by a formation of (negative) fog. On the morning of 19 January the installation operated from 0900 to 1200, at which time the fog dissipated naturally. The visibility, which was initially not over 50 to 100 meters, was raised to between 800 and 100 meters. This operation allowed 17 airliners to land and 16 to take off. On 20 January the installation operated all day; the wind was from the south. From early morning on, an opening in the cloud layer, whose thickness was estimated at 900 meters, was achieved over the airfield and in the neighborhood of Orly; it was maintained as long as the equipment was operating and

(1) P. D. Cot, Comptes rendus, Vol. 258, 1964, p. 3337.

the sun shone on the airfield a good part of the day. The operation, which according to plan was to terminate at 2000 hours, was resumed in the evening, at the request of a commercial airline, to permit three jet airliners to take off. On 21 January an opening similar to that of the previous day was obtained with a north wind. The operations of these two days made possible 76 departures and 67 arrivals. Precipitation of the ice crystals led to the formation on the ground of a layer of snow up to several centimeters deep which covered about 150 km^2 around Orly Airfield. These results were obtained with an expenditure of about 200 kilograms of propane per hour of operation."

3. Discussion of Propane Systems. This system is probably the simplest of all those tested. Once a permanent installation is made, very little maintenance is required. It is relatively cheap to operate and its operation can be made a part of the duties of the control tower operator or other airport personnel.

It does have some drawbacks: it is a flammable gas and must be kept away from any source of ignition. Also, its fumes are apt to cause temporary illness and nausea to operating personnel.

D. Seeding From Aircraft.

1. Airline Sponsored Tests. Dry ice dispersed from aircraft flying low over supercooled clouds is probably the most effective means for modifying these clouds. Although this method has been known for many years, it is only within the past year or two that it has progressed beyond the strictly experimental stage. This advancement was brought about mainly through the efforts of the United Air Lines and cooperating airports at cities in the Northwestern United States.

Essentially, the procedure used is to release crushed dry ice through a slot in the side of a light aircraft as it is flown just above the top of the fog. The flight path is selected to allow for wind drift.

In the winter of 1963-64 the UAL used this system on 14 occasions, allowing some 33 flights to operate. More than 900 passengers were able to reach destinations on time, or close to it, by these seedings. Total cost for the seeding operation was about $2500.

This winter several airports in the Northwestern United States have programs for dry ice seeding. Essentially, the contracts call for seeding with crushed dry ice about 100 feet above the top of the fog. The following amounts of dry ice are to be used:

For temperature of 32° F - use 100# dry ice

For temperature of 31° F - use 75# dry ice

For temperature of 30° - 26° F - use 50# dry ice.

2. "Cloudbuster" (USAF). A more complicated system developed by the USAF consists of an automatic dry ice pellet maker, dispersing system, and a supply of liquid CO_2. The entire unit can be mounted in the larger type aircraft and carried as standard equipment.

The recommended procedures for using this equipment is to fly a crosswind pattern on top of the clouds at an upwind distance of 40 minutes of windspeed time.

This system has the good feature of being available at all times, but it also has some undesirable features: 1) it cannot be used on light aircraft; 2) alternate landing areas are still needed; and 3) cargo or passenger carrying capabilities of the aircraft are reduced.

3. Helicopter Induced Air Exchange.

a. Description of System. Radiation and shallow advection fogs are usually covered by a layer of warmer and dryer air. When the fog is not too thick, i.e., less than 300-400 feet, a helicopter can be used to blow the overlying warm air down into the fog, causing a lowering of the relative humidity and, hence, evaporation and disappearance of the fog particles.

The technique used in this system is to fly about 50 feet above the fog at a forward speed which is slow enough to allow the helicopter time enough to blow air down to the surface: light thin fogs requiring less time, i.e., faster airspeeds, than heavy or thick fogs.

Figure 10 shows the results of one test. In this test, the cleared area was about 75 yards wide.

b. Discussion. This technique is recommended for emergency use only since it requires an unsafe flying technique: at hovering airspeed, the helicopter is operating at almost full power, at a low altitude, and in a position where an engine failure would probably cause a crash since the helicopter would have to descend through a fog to an unknown landing area.

Other drawbacks to the system are 1) the need for an alternate landing area in case the system fails, 2) the scarcity of helicopters equipped for instrument flight, and 3) the relatively small area which one helicopter can clear.

A distinctly good feature of this procedure is that it can be used on either supercooled fogs or warm fogs.

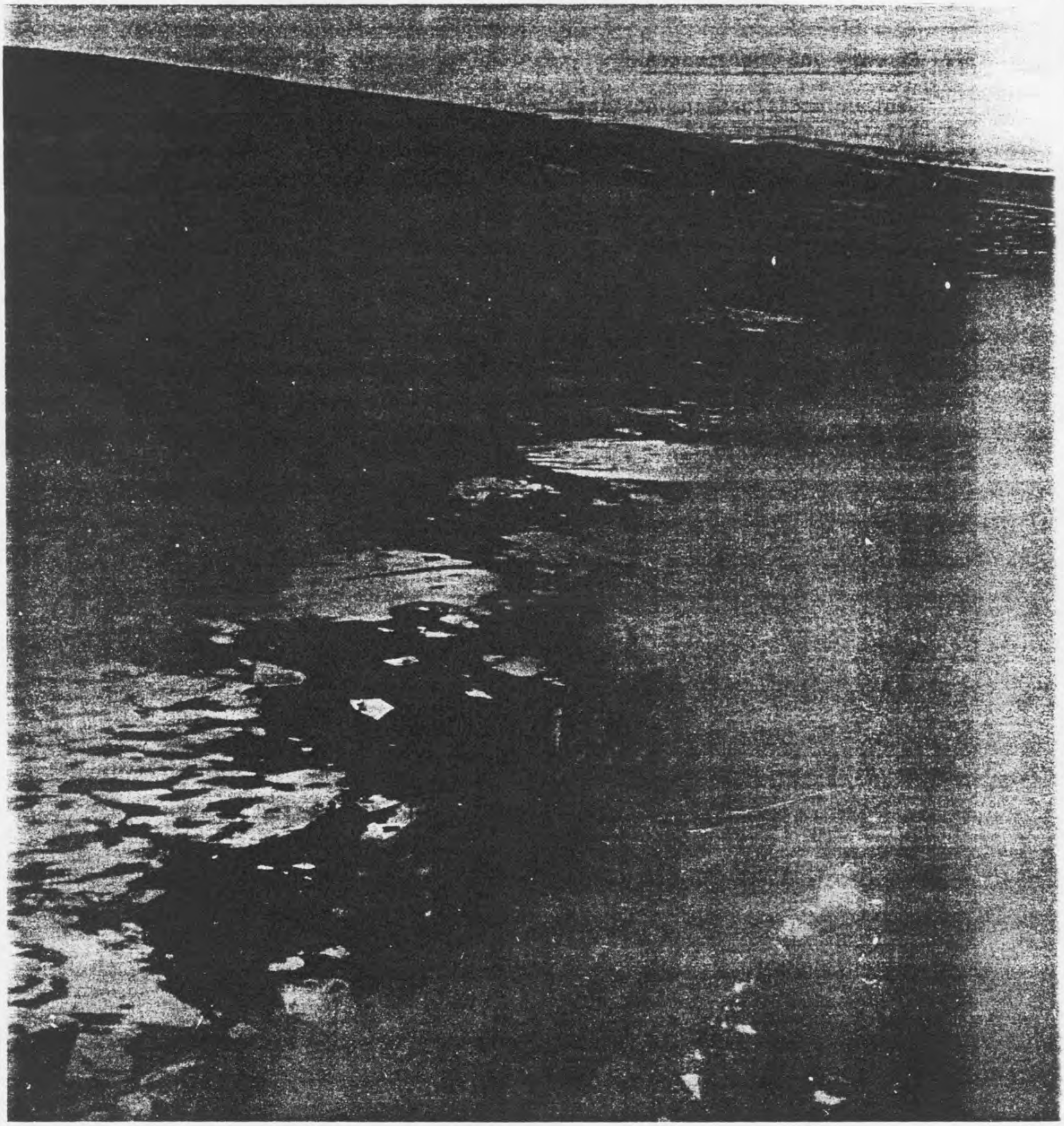

Figure 10. Area cleared by one pass of H-34 type helicopter.

IV. Summary and Conclusions

Weather modification, at least on a small scale, has risen beyond the strictly experimental phase. At least two systems for clearing supercooled fogs are known to be in operation: the propane system in use at Orly Field, Paris, France and the aircraft-dispersed dry-ice system in use in the Northwestern United States. No doubt, improvement in techniques and the acquisition of better seeding materials will bring about a complete solution to the problems imposed by supercooled fogs around airports.

Warm fog, on the other hand, is still a major problem. At the present time there is no satisfactory system for clearing this type of fog. The helicopter and vertical fan air-exchange system shows some promise but only on a limited scale.