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ICE FOG MODIFICATION BY USE OF HELICOPTERS

James R. Hicks and Motoi Kumai

September 1971

CONDUCTED FOR

ATMOSPHERIC SCIENCES LABORATORY
U.S. ARMY ELECTRONICS COMMAND

AND

U.S. ARMY MATERIEL COMMAND

BY

CORPS OF ENGINEERS, U.S. ARMY
COLD REGIONS RESEARCH AND ENGINEERING LABORATORY
HANOVER, NEW HAMPSHIRE

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PREFACE

These studies were conducted as a joint project under: 1) DA Project 1T061102B52A Task 02, *Military Aspects of Cold Regions Research*, Work Unit 10, *Cold Fog and White-out Control* (an AMC-supported project); and 2) DA Project 1T062111A126, Work Unit *Fog Dispersal Studies* (a USAECOM-sponsored project). The field work was done near Fort Wainwright, Alaska, by Dr. Motoi Kumai, Physicist, and Mr. J.R. Hicks, Research Meteorologist, of the Physical Sciences Branch, Research Division, U.S. Army Cold Regions Research and Engineering Laboratory.

The authors wish to thank Lt. Col. D.M. Bell, Chief, Plans and Operations Office, USARAL, for providing the aircraft used in these experiments; and Major J.R. Davis, CWO E.L. Bardtrief, and officers and crews of the 19th Aviation Detachment, 236th Aviation Company, stationed at Fort Wainwright; Mr. E. Alex Blomerth, USAECOM ASL; and Major Lee Snyder, USAF (presently at the University of Alaska) for their interest and support of the project.

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13. ABSTRACT

The objects of this project are 1) to increase the knowledge of the physical and optical properties of ice fog and 2) to develop techniques for its dispersal. Two series of flight tests to determine the effects of CH-47 helicopter downwash on ice fog were conducted near Ft. Wainwright, Alaska, in January 1971. During the first series, clearings were produced which were large enough for helicopter operations. This series of tests was conducted when the ice fog was in a dissipating state. The second series of tests was conducted in a denser ice fog during its developing stage. The same flight procedures were used, but clearings were not produced.

14. KEY WORDS

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INTRODUCTION

Radiation fogs, in general, are topped by a layer of warm air which is at a lower relative humidity than the fog itself. This is due primarily to a temperature inversion usually present near the surface. Ice fogs in particular are noted for the strong temperature inversions (10° to 30°C/100 m) which accompany them. When warm air from above the fog is moved downward and either mixed with or made to replace the fog, clearing results.

This phenomenon has been verified by experimentation with helicopters flying over fogs having temperatures ranging between 0° and 20°C. Hicks (1965) succeeded in clearing shallow advection type fogs which had formed over North Star Bay near Thule, Greenland. Warm radiation fogs were cleared from the Greenbrier Valley Airport near Lewisburg, W. Virginia (Plank, Spatola and Hicks 1970). The surface temperatures in the cleared zones in the latter tests were 0.3° to 3.0°C warmer than ambient, although the relative humidity remained near 100%. Clearing efforts were most effective when the fog was developing or naturally dissipating, but were much less so, or even ineffective, during the peak period when convective action was occurring. Until the present tests the effectiveness of mechanical mixing for clearing ice fogs in which the temperature may be -50°C or lower had never been demonstrated.

The physical characteristics of ice fog in the Fairbanks, Alaska, area have been studied by many scientists. Temperatures and frequencies of ice fogs were described by Oliver and Oliver (1949). Spherical ice-fog crystals were observed by Thuman and Robinson (1954) using an optical microscope. A steep inversion in an ice fog layer was measured by Robinson and Bell (1956).

Ice fog formation has been under investigation by the U.S. Army Cold Regions Research and Engineering Laboratory since 1962. Ice fog crystals were collected on electron microscope grids. After sublimation, their nuclei were examined with an electron microscope and the substrates were identified using an electron diffraction method. The majority of the nuclei were solid combustion byproducts and some were clay minerals and hygroscopic particles (Kumai 1964). Similar results were obtained by Ohtake (1967). Ice fog, as low temperature air pollution, was described by Benson (1970). Cascade impactors, carried aloft by a tethered balloon, were used to obtain quantitative samplings of ice crystals at various heights (Kumai and O'Brien 1965). Reduction of ice fog by limiting water vapor output from coal-burning facilities was investigated and measurements of aerosols in the Fairbanks area were made (Kumai 1969).

ICE FOG FORMATION IN THE TANANA VALLEY

Fairbanks and Ft. Wainwright are located in the Tanana Valley of interior Alaska. The climate of the Fairbanks area is continental, characterized by wide temperature variations, especially during the winter season. The mean daily temperature for December and January is -23°C; the record maximum is 14°C, and the minimum is -54°C. Winds are generally weak, and the mean is 1.8 m/sec with a prevailing northerly direction.

When central Alaska is covered by a high pressure system, the ground temperature decreases rapidly due to radiational cooling, and temperature inversions occur. During these periods when the air temperature is about -40°C, or below, ice fog forms from the 380,000 kg of water vapor which is emitted daily with the flue gases produced by the burning of fossil fuels in power and heating plants and in automobiles and other sources in the Ft. Wainwright area (Kumai 1969).

The ice fog remains as long as the temperature stays under about -37°C and the temperature inversion continues. The maximum height of the temperature-inversion layer is between 300 m and 1500 m when ice fog is present. The temperature difference within this layer is frequently more than 15°C.

Formvar replicas of some of the ice fog crystals present in the atmosphere during these experiments were obtained (Fig. 1). Their diameter was between 2μ and 20μ, and their concentration was estimated to be about 300 crystals/cm^3, which is about 0.1 g/m^3 of solid material.

Although ice fog is the principal weather hazard to aircraft operating at extremely cold temperatures, blowing snow produced by helicopter downwash during landing and takeoff causes a very serious visibility problem. Figure 2 shows some replicas of the solid material found in the turbulent area surrounding a helicopter during takeoff in an ice fog. They consist of some ice fog particles and some fragments of snow crystals lifted from the runway.

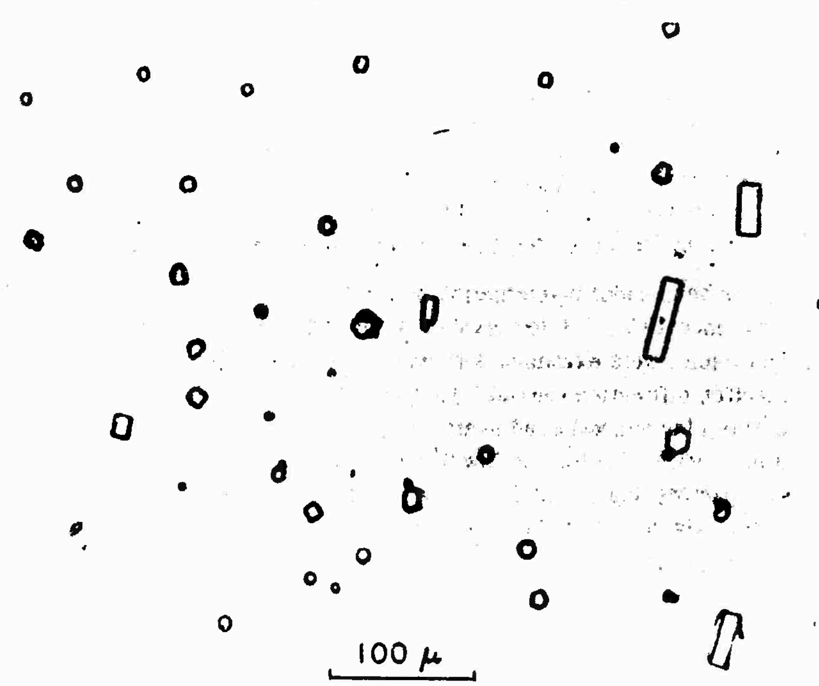


Figure 1. Ice fog crystals formed at an air temperature of -40°C.

Figure 2. Ice fog and snow crystals found near helicopter during takeoff.

MECHANISM OF ICE FOG DISPERSAL BY HELICOPTER DOWNWASH

One known mechanism of ice fog dispersal is as follows. Relatively warmer and drier air from above is forced down by the helicopter and mixed with the ice fog. This mixing reduces the relative humidity in the fog, allowing the ice crystals to sublime and disappear.

One important parameter governing the effectiveness of this system is the amount of air (mass flux, F_m) which is forced downward. For the CH-47 Chinook helicopter, this is about 6527 kg/sec for standard gravity (9.80665 m/sec²) and about 6549 kg/sec for the conditions present during these tests. These values are found by the following relationship (Plank, Spatola and Hicks 1970):

$$F_m = \sqrt{\frac{\pi D^2 Mgd}{4}} \text{ kg/sec}$$

where:

D = 18.02 m, the rotor diameter of the CH-47

M = 12,247 kg, the mass of the helicopter

g = 9.82210 m/sec², the acceleration of gravity at 64° 50'N latitude and 215 m above sea level

d = 1.3982 kg/m³, the density of air at 996 mb and -25°C at flight level

Other parameters affecting visibility are downwash velocity and water production from burning fuel.

Downwash velocity (V)

A value of 18.4 m/sec for the CH-47 helicopter is obtained from the relationship:

$$V = \sqrt{\frac{4\,Mg}{\pi D^2 d}}\ .$$

During landing and takeoff, this high air velocity is capable of lifting snow and ice particles from the runway and reducing the visibility to less than 1 m.

During hover flight, the downwash penetration distance is governed by the initial velocity of the air, as it leaves the rotor blades, and the temperature gradient of the underlying air. A penetration distance of about 244 m (800 ft) was observed during one test. In theory, the higher the initial velocity, the deeper is the fog clearing capability of the helicopter.

Water production from burning fuel

During high relative humidities and temperatures below -37°C, heavy fogs can be produced by the burning of fossil fuels. The CH-47 helicopter used in these tests consumed fuel at rates of 275 g/sec during normal cruise and 350 g/sec during hover, and produced water at the rates of 380 g/sec and 480 g/sec, respectively, resulting in the addition of about 0.1 g of water to each cubic meter of air in the downwash.

ICE FOG DISPERSAL TESTS

During the period 7-14 January 1971, two series of ice fog dispersal tests were conducted near the Fairbanks and Ft. Wainwright, Alaska, area. A CH-47 Chinook helicopter flying just above the fog was used to produce the needed downwash. An Army UH-1 helicopter flying about 130 m above and behind the CH-47 was used to carry the flight director who also was the observer and photographer. The results of these tests follow.

Test series of 9 January 1971

Ice fog (30 to 50 m thick) was present in the populated areas. Visual range varied between 100 and 300 m in the fog and changed with location, time and wind. The surface temperature was -39°C; at flight level it was -25°C. The ice fog conditions and the CH-47 used for the tests are shown in Figure 3.

The aircraft departed the ramp area in front of hangars 4-5 at Ft. Wainwright at 1240 hours and proceeded to an area of dense fog south of the power plant and cooling pond. The fog there showed some convective action, the most intense being closest to the power plant.

Several targets of opportunity were used with varying heights, airspeeds, and flight patterns being flown. Results of these runs are:

1. Generally, the first attempt to clear an area was the most successful. Repeated passes did not improve the visibility; in fact, they usually caused a denser, turbulent appearance in the stirred area, even though no direct condensation or vapor trail was observed behind the helicopter.

2. The nearer the flight path came to the source of moisture, i.e. the power plant and cooling pond, the more difficult it was to clear a path. In most cases, it was not accomplished at all.

3. Several clearings (Fig. 4a, b, c) were made in the more quiescent areas, most notable of which was the first pass along a power line. This cleared path (Fig. 4a) could easily have been used to land helicopters and perhaps light fixed-wing aircraft.

Figure 3. Ice fog and CH-47 helicopters.

4. In all cases, the clearings remained open for less than one minute.

5. The ice fog remained in the area for about 24 hours after the tests; however, it is believed that it was in a dissipating stage when the tests were made.

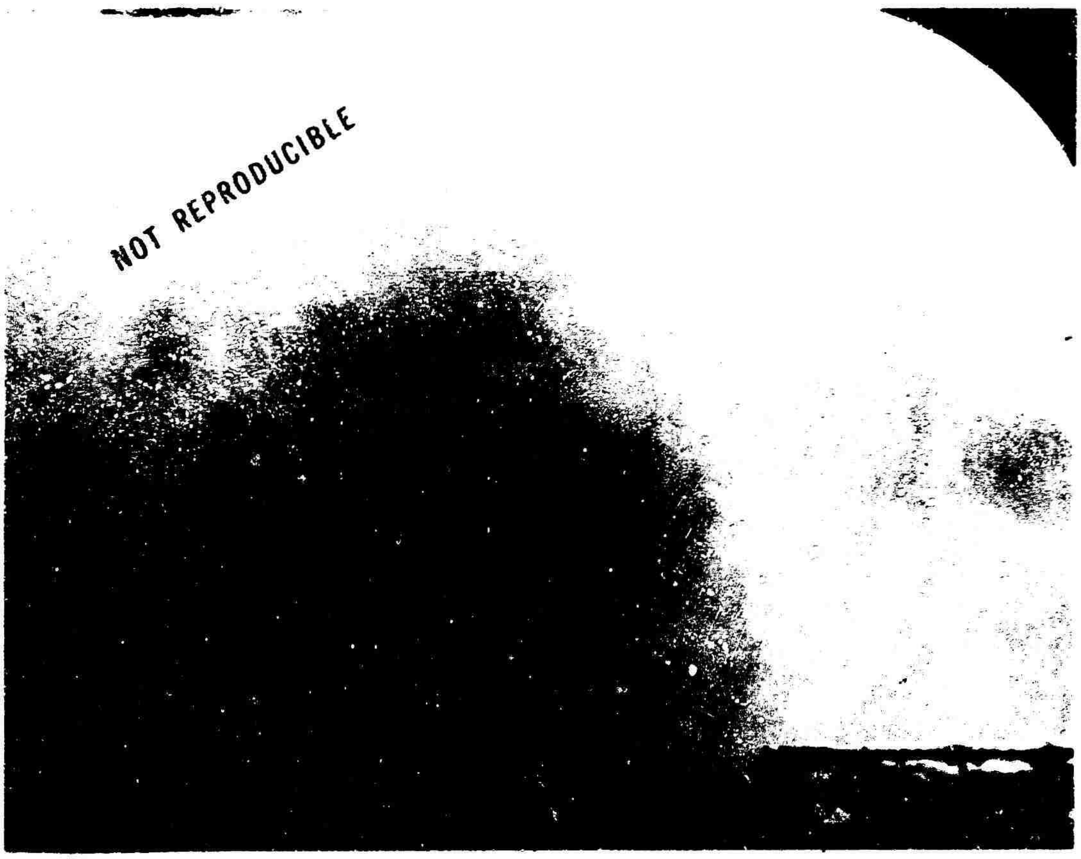
Test series of 14 January 1971

A dense ice fog (30-50 m thick) in its developing stage covered much of the Fairbanks-Ft. Wainwright area. Surface temperature was -40°C (1° colder than during the 9 January tests) and temperature at flight level was -26°C.

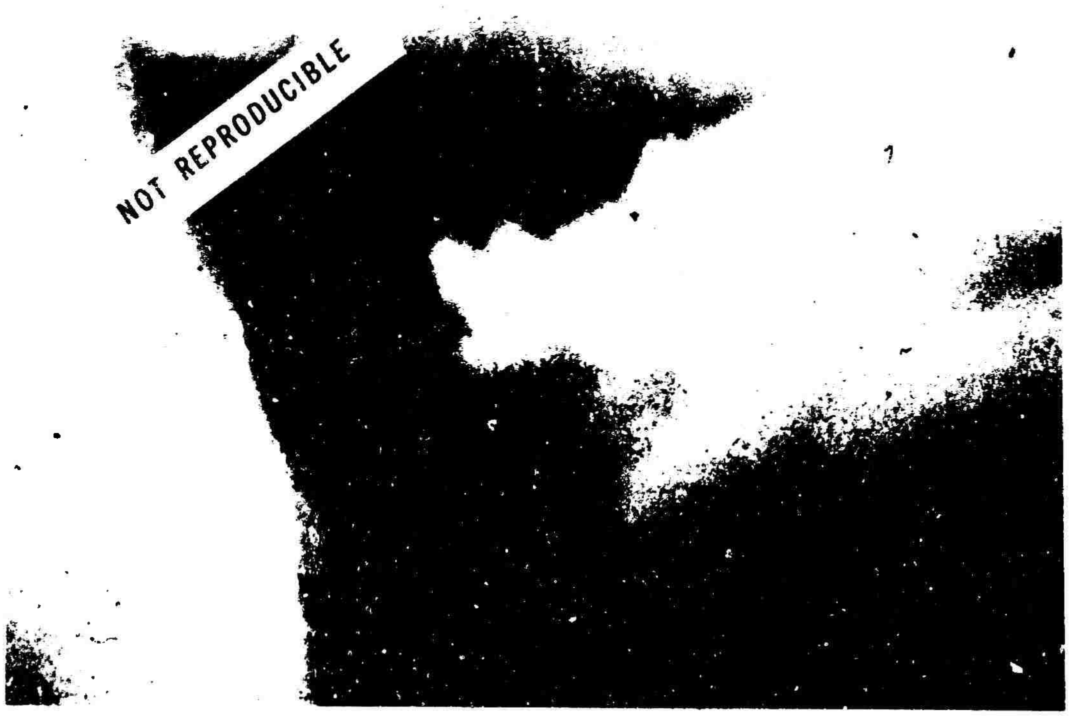
Relative humidity above the fog top was not measured, but was near saturation as indicated by the condensation noted near the rotor tips during extremely slow flight and hover periods.

Generally, the same flight procedures used in the previous tests were followed, i.e. an undisturbed area was selected and slow flight or hover was executed. No clearings were established during this series of tests. In areas of light fog, conditions were worsened by the helicopter flights, and in the denser area an actual increase in fog density and depth was observed. In several nearby clear areas, slow flight and hover at about 50 m above the surface caused no change in the unlimited visibility, indicating that the water vapor content changes very abruptly in the horizontal.

This particular ice fog continued to cover the area for more than four days and was undoubtedly in the growing stage during these tests.

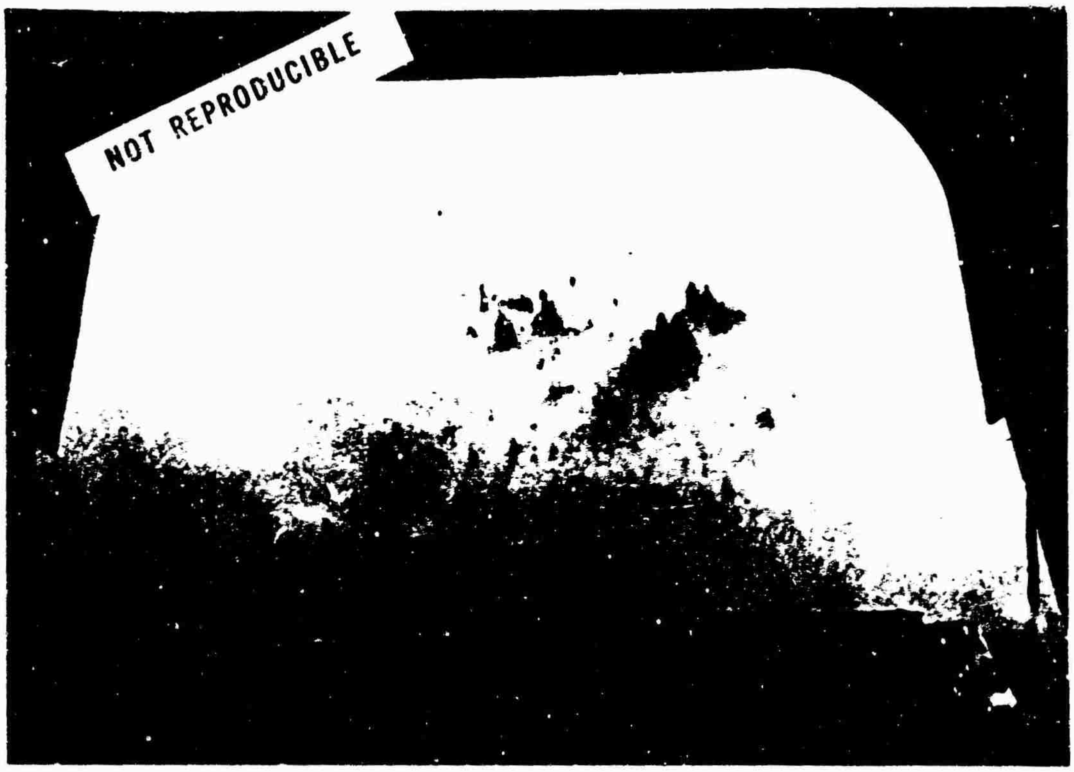


a



b

Figure 4. Views of ice fog clearings by the downwash created by a helicopter. (Photo by Maj. L. Snyder.)



c

Figure 4. (Cont'd).

CONCLUSIONS AND RECOMMENDATIONS

These tests have demonstrated that clearings in ice fog large enough to allow VFR helicopter operations can be made under certain limited meteorological conditions, such as those present in a dissipating ice fog, and that no clearings can be created under other conditions.

It is recommended that research be continued to determine:

1) All meteorological conditions under which clearing can be accomplished.

2) The actual process or combination of processes by which clearing can be accomplished. Three possibilities are:

a) The mixing of warm and less humid air with the fog by the helicopter downwash causing sublimation and disappearance of the ice crystals. This process has been verified in these tests as well as in warm and supercooled fog.

b) The adding of moisture from the burning fuel of the aircraft engines causing an increase in size, and subsequent rapid precipitation of the ice fog particles. This hypothesis is in direct opposition to that stated in (a) above; however, light precipitation and subsequent clearing have been observed after the passage of aircraft through ice fog.

c) The changing of the temperature structure above the fog in those cases where helicopter downwash does not actually penetrate into the fog. Through adiabatic compression and actual displacement downward of the warm air, an increase in the temperature of the air overlying the fog is accomplished. This may have an effect on the underlying fog by thermal radiation and conduction favoring fog dissipation.

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