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ABSTRACT

The first part of this presentation concentrates on operational programs in the dissipation of supercooled fog as conducted by U. S. commercial and military agencies with emphasis on that of the U. S. Air Force's Air Weather Service (AWS). This program involves airborne dissipation systems at Elmendorf Air Force Base, Alaska, and at U. S. bases in Germany, as well as ground-based propane systems at Fairchild Air Force Base, Washington, and Hahn Air Base, Germany.

The second part reviews progress in warm-fog dissipation which is mostly in the research and development stage. The French jet-engine installation is noted along with proposals for warm-fog dissipation by heat techniques prepared by several U. S. commercial companies and by helicopter downwash as advanced by the Air Force Cambridge Research Laboratories (AFCRL). Information is presented on recent tests, using hygroscopic materials, conducted by AFCRL, AWS, and the Navy Weapons Center.

INTRODUCTION

In addition to his tremendous technological advances in space research, during the past decade man has achieved considerable progress in attempting to alter certain types of meteorological conditions in his own earth environment. Research in weather modification generally has been pursued along four principal lines:

1. precipitation augmentation,
2. hail or lightning suppression,
3. hurricane modification,
4. fog and stratus dissipation.

Although the future holds promise for the implementation of all of these schemes on other than just a research basis, at this time only the procedures involved in dissipating certain types of fog have been tested often enough, and have yielded results reliably enough, to be categorized as truly operational. As research to date has not yielded any insight into how fogs composed entirely of ice crystals can be alleviated, only methods of dissipating fogs comprised of liquid drops, either in a supercooled or in a "warm" state, will be discussed here.

PHYSICAL BASIS FOR FOG DISSIPATION

a. Supercooled Fogs.

It readily can be observed that water droplets in a clean environment can remain in a metastable supercooled liquid state at temperatures between 0C and -40C. A change to the ice phase can be accomplished either by cooling the environment to a temperature colder than -40C (homogeneous nucleation), or by supplying to the environment those nuclei which enable the phase-change energy barrier to be overcome (heterogeneous nucleation). Because the vapor pressure over ice is less than that over water at the same supercooling temperature, any ice particles formed within a fog will tend to grow at the expense of the liquid drops. In this manner, a great many (several hundred cm^{-3}) small ($10\,\mu m$) liquid droplets can be "converted" into a relatively fewer number (several cm^{-3}) of larger ($100\,\mu m$) ice particles with an attending improvement in visibility. The ice particles thus formed may eventually grow large enough to fall out of the fog as snow, thereby creating a considerably greater improvement in the visibility.

b. Warm Fogs

The physical basis for dissipating fogs which persist at temperatures warmer than 0C centers upon the possibility either of decreasing the ambient humidity enough to cause evaporation of the water droplets, or of initiating a coalescence process within the fog volume to create rainout. Seeding with small particles of hygroscopic material (such as NaCl) can result in a combination of the above two effects. Such particles have the capacity to absorb water vapor at relative humidities greater than about 75%, and thus can act both to effect a transfer of moisture away from the fog's liquid drops and, due to their preferential growth, to initiate a coalescence mechanism by creating a spread in the fog's drop-size distribution. Alternative dissipation schemes rely upon lowering the humidity below water saturation in portions of the fog volume by the application of techniques designed either to add sensible heat or to entrain drier environmental air. It can be calculated that, assuming an air temperature of 10C and a fog liquid-water content of 0.3 $gm\ m^{-3}$, it is necessary to warm the air only an additional half-degree Centigrade to enable it to hold the vaporized fog water. Other computations indicate that if the air immediately above a shallow (100m or less) fog layer is relatively warm and dry, it is within the realm of possibility to evaporate the fog droplets by artificially mixing the two layers.

TECHNIQUES AND RESULTS OF FOG-DISSIPATION OPERATIONS

a. Supercooled Fogs

Because methods to induce heterogeneous nucleation have not yet proven to be effective in the atmosphere at temperatures warmer than about -5C, techniques to dissipate supercooled fogs on an operational day-to-day basis rely upon producing severe localized cooling to initiate the ice phase by homogeneous nucleation. Although any chemical substance with the capability of cooling the immediate environment with which it has contact to a temperature colder than -40C can initiate nucleation, in practice--for reasons of economy, safety, and ease of handling--only solid CO_2 (dry ice) and liquid propane have received widespread use.

The Air Force Air Weather Service (AWS) has conducted numerous fog-dissipation operations both in Alaska and in Europe using dry ice as the seeding agent and an airborne WC-130 as the seeding platform. Using aircraft to dispense the seeding agent adds flexibility to the range of operations. In Europe, for example, one group of three aircraft has been used to service seven military bases in Germany and one in England. Further, employment of aircraft permits making up-to-the-minute compensations for fluctuations in meteorological parameters such as wind speed and direction. Such fluctuations in wind speed and direction can be critical to the success or failure of a seeding operation because of the time interval (at least 45 min) necessary for the ice crystals to grow to a size large enough for them to fall out and create a clearing. Normal operating procedure is for the aircraft to fly just above the top of the fog layer, dispensing the dry ice far enough upwind to allow time for the formation of a clearing which can be advected over the target area.

Typical results from an airborne, dry-ice seeding operation at Ramstein Air Base, Germany, are depicted in Figure 1. On the morning of 13 January 1970, dense fog covered most of central West Germany. At Ramstein the fog layer was approximately 200m deep with a surface temperature of -3C. The surface winds were from the east at 2 knots, and the seeding pattern, which extended from the west end of the active runway to about 10km east, was flown to provide a two-hour useable clearing. Seeding commenced at 0804L and some improvement in visibility was noted at 0900L (Figure 1b). Visibility continued to improve until after 1000L (Figure 1d), but a wind shift to the northeast advected more fog over the field. By 1034L (Figure 1e) the visibility again dropped below field minimums. A second seeding pattern was initiated at 1051L to the northeast of the runway and extending in that direction for about 12km. By 1210L (Figure 1g) the field again had gone above the minimum of a 100m ceiling and a 1.6km runway visual range (RVR). Post-analysis indicated that the prevailing winds should have maintained the resultant clearing over the runway for a ten-hour period. The field actually dropped below minimums again at 1943L, some nine hours after the start of seeding. No other valley-located airfield in central West Germany was open to traffic on 13 January. The best estimates are that, without the seeding operation, Ramstein would not have gone above minimums at any time during the day. The seeding operation was credited with assisting the arrival of 34 aircraft and the departure of 32. This example is illustrative of the more than 200 take-offs and 150 landings made possible in Europe during the past two years by the AWS airborne seeding program.

The AWS airborne operation at Elmendorf Air Force Base, near Anchorage, Alaska, in addition to attempting to clear the airfield after it already has dropped to a visibility below acceptable standards, is designed to seed preventively. On days when fog forms upwind and is expected to move over the airfield, seeding is initiated to prevent the field from falling below minimums. During the past two years, best estimates indicate that nearly 350 aircraft have been able to take off, and nearly 300 have been able to land, which, without the seeding operation, would not have been able to do so. Only 21 aircraft have had to divert from Elmendorf because of supercooled fog conditions in the two years of the operational seeding program there. In actuality not more than three of these diversions can be attributed to failure in technique. The others are attributed to operational and forecast problems. A detailed report of the entire AWS airborne supercooled-fog-dissipation program is available(1).

Airfields which either experience a particularly large number of hours of supercooled fog annually, such as Fairchild Air Force Base near Spokane, Washington, or are very important centers of commercial transportation, such as Orly Airport in Paris, France, can be served better by a semi-permanent ground-based seeding installation. Tests have shown that the dispensing of liquid propane into a fog layer from the top of a short tower is an effective, safe, and economical measure for initiating the ice phase in supercooled fogs. The desired flow-rate of propane is achieved by varying the size of the nozzle through which it is sprayed.

The propane network at Fairchild consists of 22 dispensers positioned around the field in such a manner that, based on climatology, they are at the proper distance and direction upwind of the instrument runway to protect against most supercooled-fog occurrences. With the towers spaced about 1km apart, as at Fairchild, and a steady wind not varying greatly in direction, adequate clearings can be produced with the operation of just four or five dispensers.

An example of a fog-dispersal operation at Fairchild that illustrates what ground-based equipment of this type can accomplish took place in December 1969 in support of a special military flying operation. Prior to seeding, the fog layer was about 300m deep and the runway visibility was less than 1000 ft. Within 55 minutes after seeding the runway visibility had increased to over 1/2 mile and, within an additional 20 minutes, a clearing extended three miles in the direction of the wind and was two miles wide. At the same time, the visibility just upwind of the dispensers was reported to be less than 1/4 mile. The clearing was maintained over the airfield for four hours while 32 aircraft departed. During the past two years at Fairchild, more than 80 take-offs and nearly 50 landings have been made possible by operational ground-based seeding with liquid propane. Such success has led to the testing of a similar system at Hahn Air Base, Germany; this has not yet been fully tested in an operational mode.

b. Warm Fogs

In contrast to the great success achieved in operationally dissipating supercooled fogs, no generally accepted system for the routine, operational dissipation of warm fogs is yet available. However, research into the problem is proceeding along several different lines, and some of the preliminary results are encouraging.

During World War II a crude thermal fog-clearing system called FIDO (Fog Investigation and Dispersal Operation) was operated in England with some limited success. Basically, this system relied upon the burning of gasoline alongside a runway to input enough heat energy to evaporate the liquid fog droplets. A more refined postwar system was designed using clean-burning, high-pressure fuel-oil burners, but, because of a prohibitive cost-efficiency ratio, it never came into general use. The principal drawback of a system such as FIDO is its inability to augment mixing between the heated air and the fog in order to distribute enough heat throughout the runway volume to produce adequate clearings.

Experiments have been conducted recently by both AWS and the Paris Airport Authority on the use of jet engines as a heat source for warm-fog dissipation. In addition to the heating, the engines provide the turbulent energy required to mix the hot exhaust with the foggy air over the runway. Some loss of efficiency occurs because the burning of jet fuel releases additional water vapor to the air. Nevertheless, a pilot project carried out by AWS at Travis AFB, California,[2] clearly demonstrated that the heat and mixing generated by four C-141 jet aircraft parked alongside the runway are sufficient to improve the visibility and ceiling in dense fog to well above minimum conditions. Such improvement, however, lasts only as long as the heat input is continued. It is estimated that a permanent installation of vented jet engines alongside a runway would be economically feasible at airports which are susceptible to many hours of warm-fog conditions and which handle large amounts of traffic. A prototype for such a system has been installed and is being evaluated at Paris' Orly Airport.

A second avenue of approach to the warm-fog dissipation problem has been explored by the Air Force Cambridge Research Laboratories (AFCRL) in conjunction with the Army's Atmospheric Sciences Laboratory[3]. A series of experiments at Lewisburg, West Virginia, has indicated that, under certain conditions, the downwash from a helicopter hovering above a layer of ground fog is capable of forcing entrainment of enough dry air to create clearings through which at least helicopters and VTOL aircraft can be landed. Some of the important factors determining the effectiveness of such a clearing operation are the depth of the fog layer, the temperature and humidity of the clear air above the fog, the type, size, and weight of the helicopters used to stir the air, the environmental stability, and the natural state of the fog (i.e., whether forming, stable, or dissipating) at the time of the test. It appears that using helicopters to create sizable clearings can work if the fog layer is not deeper than about 100m. It should be mentioned also that the downward-moving wake vortices from fixed-winged aircraft theoretically could work to create clearings in a similar manner.

Clearing warm fogs by seeding with hygroscopic materials has received much attention during the past two decades, but the technique still must be placed in the research and development stage. Results from computer modelling and laboratory experiments leave little doubt that the theory of using hygroscopic material to absorb enough water vapor to subsaturate portions of a fog volume and to cause evaporation of the fog droplets essentially is sound, but the logistics of applying such a technique to the atmosphere are formidable. The critical factor is time. The hygroscopic particles must be given sufficient time to absorb enough vapor to create a noticeable effect, and, in this regard, the initial size of the particle is crucial. Particles too large will fall through the fog layer without absorbing enough water, while particles too small may not grow large enough to fall out of the fog and could conceivably decrease the visibility. Perhaps more importantly, the fog must be seeded far enough upwind to allow time for the growth process to produce a clearing over the target area, and this requires an accurate knowledge of wind speed and direction. However, the winds associated with warm-fog conditions, though often light, frequently exhibit considerable variation both in speed and direction. When a target area as small as a runway is considered, any minor changes in either wind speed or wind direction can cause the operation to fail. The targeting problem probably could be alleviated by seeding an area large enough to enable at least some part of the resultant clearing to drift over the runway. This, of course, greatly increases the logistics of the operation, and leads to a reduction in cost-benefit ratio.

A number of successful warm-fog clearings induced by hygroscopic seeding have been reported in the literature. For example, Kocmond et al[4] at the Cornell Aeronautical Laboratory describe a case where seeding a 100m-deep fog layer with urea was able to increase the surface visibility by more than a factor of two within 15 minutes. Accompanying the change was a shift in the fog's droplet spectrum from a mean volume diameter of 17 μm to one of 29 μm and a decrease in droplet concentration from 37 cm^{-3} to 5 cm^{-3}. AFCRL has had some similarly encouraging results from an experimental field project in the Noyo River Valley region of California, and research with microencapsulated urea as a seeding agent recently was conducted at McClellan AFB near Sacramento, California.

Tests to determine the operational readiness of a seeding system employing a hygroscopic solution were carried out this past January by AWS at McClellan.(5) The seeding agent used was a highly concentrated nitrate-urea solution. The results from a limited test sample indicate that hygroscopic seeding is not able as yet to produce a required clearing over a runway target with enough reliability to be classified as an operational technique. This conclusion stems primarily from the difficulties expected in targeting the small clearing effects should they occur.

The list of possible measures to dissipate warm fog has not been exhausted, but the three described (i.e., jet-engine heating, helicopter-downwash mixing, and hygroscopic seeding) probably hold the most promise for providing an eventual solution to the problem on an operational basis.

SUMMARY AND CONCLUSIONS

Man now has the capability to dissipate supercooled fogs on an operational basis. This has been achieved through the use of a refrigerant, either dry ice or liquid propane, to cool the air to a low-enough temperature to initiate the ice phase and cause, by the Bergeron-Findeisen mechanism, a flux of moisture from the fog droplets to the ice crystals. The dispensing system can be either airborne or ground based. AWS has had great success with airborne dry-ice seeding in Alaska and in Europe and ground-based liquid-propane seeding in the state of Washington. During the past two years at bases where these techniques have been employed, best estimates suggest that more than 600 aircraft take-offs and over 500 aircraft recoveries have been assisted.

As yet, no such operational capability exists for the dissipation of warm fog. Several techniques, including jet-engine heating, helicopter-downwash mixing, and hygroscopic seeding, have met with varying degrees of success in field research projects, but none is yet ready for implementation on a routine, operational basis.

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REFERENCES

(1) Air Weather Service, "A Summary of Field Activities Conducted Under MAC Operational Order 4-4-69 Airborne Cold Fog Modification," Final Report, June 1970.

(2) Appleman, H.S. and Frank G. Coons Jr., 1970: The Use of Jet Aircraft Engines to Dissipate Warm Fog. J. Appl. Meteor., 9, 464-467.

(3) Plank, V.G., A.A. Spatola, and J.R. Hicks, 1970: Fog Modification by use of Helicopter. Preprints - Second National Conference on Weather Modification, Amer. Met. Soc., Boston, 117-121.

(4) Kocmond, W.C., P.J. Pilie, W.J. Eadie, and E.J. Mack, 1970: Recent Fog Modification Research at Cornell Aeronautical Laboratory. Preprints - Second National Conference on Weather Modification, Amer. Met. Soc., Boston, 112-116.

(5) Air Weather Service, "A Report of an Air Weather Service Evaluation of a Possible Technique to Dissipate Warm Fog," Final Report, February 1971.

ILLUSTRATIONS

Figure 1. Photographs showing clearing following seedings at Ramstein AB 13 January 1970.