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PROJECT FOG DROPS

INVESTIGATION OF WARM FOG PROPERTIES AND FOG MODIFICATION CONCEPTS

QUARTERLY PROGRESS REPORT

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I. INTRODUCTION

The Office of Aeronautical Research of the National Aeronautics and Space Administration has authorized this Laboratory, under Contract No. NASr-156, to investigate warm fog properties and possible fog modification concepts. During the first four years of research the program emphasized analytical and experimental work on:

1. Models of the micro- and macroscopic properties of warm fogs.

2. The characteristics of aerosol droplets and means of favorably altering these properties, such as by enhancing the growth or evaporation rate of otherwise stable aerosol droplets.

3. The design and construction of apparatus for measuring fog characteristics, for simulating certain fog conditions and for measuring cloud and fog nucleus concentrations.

4. Field observations to obtain more information about the properties of natural fog.

5. Formulation and evaluation of fog modification concepts based on the above findings, as well as a review of other possible techniques.

6. Assessment of the supercooled fog problem in the United States and specification of the geographic areas where an operational seeding program might be practical.

During year IV a technique for seeding warm fog was successfully demonstrated in large scale laboratory experiments. Plans for this year include field tests of the concept at Buffalo International Airport.

This report briefly describes accomplishments of the first quarter of the fifth contract year. Tasks for the next quarter are outlined.

II. TECHNICAL DISCUSSION

Work has progressed in four major task areas during the past quarter. These areas are: (1) theoretical modeling of fog modification, (2) a climatic survey of fog frequency in the Buffalo, New York area, (3) large scale laboratory experiments to test different size distributions of NaCl nuclei and also to test the effectiveness of seeding fogs with urea, and (4) planning and preparations for field testing of the proposed seeding concept.

A. Theoretical Modeling of Fog Modification by Seeding with Hygroscopic Nuclei.

A computer program has been developed to simulate the response of natural and artificial fogs to seeding with hygroscopic nuclei. In order to model the effects of the sedimentation of saline droplets and provide an accurate description of the vertical variation of visibility and other fog properties, the model fog may be divided into several horizontal layers of equal thickness. The initial supersaturation, size distributions of fog droplets and salt particles, and cooling rates, if any, in each layer are specified at the beginning of a simulation. The coupled differential equations describing the time rates of change of supersaturation and the size of the fog and saline droplets are then integrated numerically in discrete time steps to establish the temporal evolution of these quantities and related fog properties such as visibility and liquid water content.

The Stokes terminal velocity and the height of each of the initial size classes of saline droplets are computed at every time step. The droplets in each of these size classes grow under the supersaturation conditions prevailing in the layer in which they are found, along with all of the other size classes of fog and saline droplets present in the layer at that time. Thus, as a saline droplet falls through the fog, it may extract moisture from successively lower fog layers. Sedimentation of the natural fog droplets (which is very slow) is neglected in the present model.

Initial experiments with this model have been largely restricted to the verification of the program by comparison of results with earlier analytic calculations of saline droplet growth (Kocmond and Jiusto, 1967), and preliminary estimates of salt-seeding requirements for the effective clearance of a hypothetical airport fog. Some computed curves of visibility in various fog layers as a function of time are shown in Figure 1 for the following fog and seeding conditions:

(a) Temperature 20°C

(b) Cooling rate 1°C per hour

(c) Fog depth 100 m

(d) Fog droplet radii 5μ

(e) Fog liquid water content 0.2 g m^{-3}

(f) Salt (NaCl) uniformly injected throughout fog at time zero

(g) Salt particle radii (dry) 4.8μ

(h) Salt particle mass 10^{-9} g.

From Figure 1, it is seen that while the 1 mg m^{-3} salt concentration is marginally effective, the 2 mg m^{-3} salt concentration produces large visibility improvement at all levels. For a fog volume of 10^8 m^3, equivalent to a zone 500 m wide, 100 m high, and 2000 m long, the 2 mg m^{-3} concentration corresponds to a 200 kg salt mass per seeding.

The visibility curves at the 0-20 m and 40-60 m levels for the 2 mg m^{-3} salt concentration are of particular interest. At both levels, the computed visibility increases from 65 m to almost 300 m in about five minutes after seeding and then levels out - showing only a slow degradation in visibility due to the cooling, until the last of the saline droplets which have fallen into the layer from above begin to sediment out of the layer. The leveling out of the visibility occurs when the fog droplets have evaporated to less than 1μ radius and the supersaturation has been reduced to the extent that the saline droplets, falling into the layer from above, produce no further improvement in visibility. The visibility is then essentially limited by the saline droplets which have reached approximately 30μ in radius. When the last of the

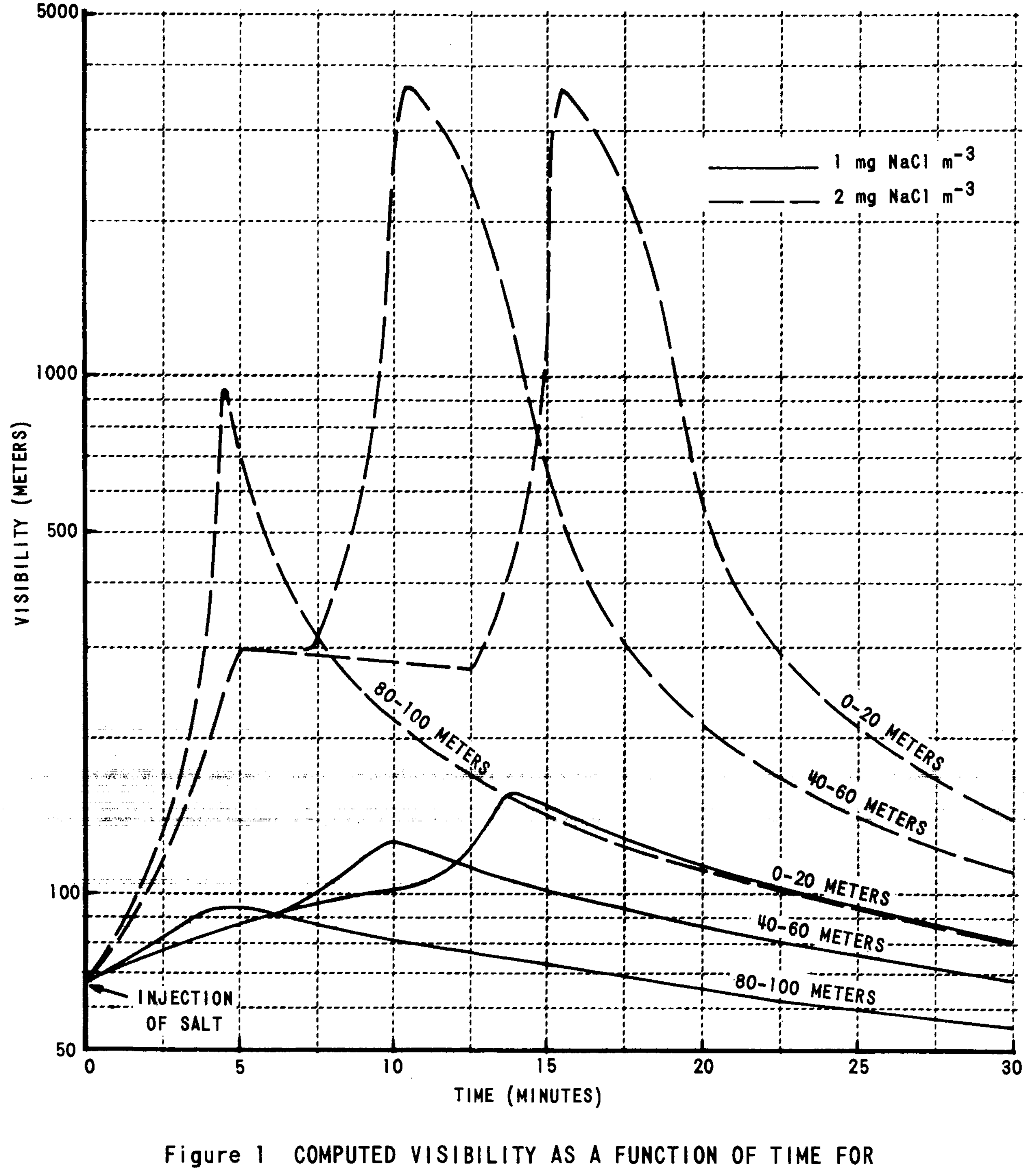

Figure 1 COMPUTED VISIBILITY AS A FUNCTION OF TIME FOR UNIFORM SEEDING OF A HYPOTHETICAL AIRPORT FOG WITH 1°C PER HOUR COOLING.

saline droplets fall out of the layer, a great improvement in visibility is produced. Subsequent degradation of visibility is due to the regrowth of the fog droplets under the 1°C per hour cooling used for these calculations (a rate which is significantly larger than expected in nature). If the mixing produced by turbulence in an actual fog situation significantly reduces the effective sedimentation rate of the saline droplets, the peaks in the visibility curves would be diminished somewhat and broadened.

In the future, it is anticipated that the ability of this computer model to simulate the effects of various seeding materials, nucleus-size distributions, and seeding methods on different fog types will produce valuable inputs to the planned field experimentation program.

B. Climatic Survey of Fog Frequency in Buffalo, N. Y.

A detailed survey was conducted to determine the frequency of fog occurrence, fog density and duration in the Buffalo, New York area. As part of the study we determined the average number of fogs per month that could be considered suitable for seeding. The criteria used in selecting seedable fogs were as follows:

1) fog duration of at least three hours,

2) wind speed <10 knots

3) minimum visibility $\leq$ 1/2 mile

Of all fogs surveyed, only a small percentage were classified as seedable. In Table I, the data are summarized according to month.

TABLE I

Mean Number of Seedable Fogs at Buffalo, N. Y. (18 year average)

Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1.0	1.5	2.5	2.4	1.1	1.3	1.0	1.6	0.8	1.0	1.5	1.5

It is apparent from these data that the late winter and early spring months are best suited for conducting seeding experiments. All other times of the year are similar in fog frequency.

If there are not ample opportunities for seeding in Buffalo during the period April-August 1968, we plan to move our seeding apparatus to the Ashford, New York area where radiation fogs often form in the valley areas during the fall months. These plans, of course, will be contingent on the results of seeding trials during the next few months.

C. Large Scale Laboratory Experiments.

For a one-week period in November 1967, fog seeding experiments were conducted in the CAL Ordnance Laboratory at Ashford, N.Y. These experiments were designed to test the effectiveness of seeding fogs with different size distributions of NaCl nuclei, and also to examine the behavior of fogs seeded with urea crystals of prescribed sizes. Certain of the experiments were witnessed by our NASA Project Monitor, Mr. William McGowan. Since data analysis is just beginning, only a brief summary of the experiments are presented here.

Instrumentation for monitoring the effects of seeding included transmissometers at two levels (4 feet and 15 feet above the chamber floor), thermocouples for making temperature measurements at the chamber top and bottom, a G. E. Small Particle Detector for measuring total nucleus concentration, and a droplet sampler.

A total of 27 experiments were run. Emphasis was placed on determining the optimum seeding payloads for dissipating fog in the 600 m^3 volume and also on evaluating the effect of different size distributions of seeding material. NaCl and occasionally urea* nuclei of controlled size were used in the experiments. During the latter part of the experimental period, tests were conducted to determine the effect of seeding fogs having initial visibilities of about 700 feet. Finally, three tests were run to determine the effect of re-seeding fogs several minutes after initially injecting nuclei into the fog.

* Provided by W. R. Grace Chemical Company, Clarksville, Md.

A summary of the results are presented in Tables II and III. Table II shows the maximum visibility improvement (seeded fog relative to control fog) due to seeding with the indicated material. The minimum visibility at the time of initiating the secondary expansion (required to maintain dense fog) is also indicated. Table III shows the results of fogs seeded more than once. The technique used in the sequential seeding experiments was to seed, as always, shortly after completing the initial fog-forming expansion. A second seeding was effected several minutes later, after the visibility improvement caused by the initial seeding had apparently leveled off.

Several pertinent features of the data in Tables II and III are summarized below:

1) Visibility improvement factors are greatest for fogs having an initial visibility of ~ 700 feet. This result is particularly meaningful in view of the realistic fog densities involved in the experiments. Natural fogs of 100' to 200' visibility are infrequent in the Buffalo area.

2) The maximum improvement in visibility that results from seeding with urea nuclei of prescribed size is about the same as that produced from NaCl seeding. Not apparent from the data, but nonetheless a serious problem, is the clumping character of urea crystals. The importance of avoiding clumping can be recognized by comparing results obtained in experiment 10, in which clumping was serious, with results of experiment 12 in which there was very little clumping.

3) Two seedings of a single fog are about as effective in causing dissipation as one seeding using the same total mass.

4) Use of very large (44-125μ) NaCl nuclei is effective in dissipating laboratory fog but impractical for field application because of the greater seeding mass requirements. As expected, the NaCl distribution having a modal diameter of 8μ produced more rapid clearing of the fog than the smaller particle size distribution. Total visibility improvement is comparable for all three NaCl distributions used.

Table II

VISIBILITY IMPROVEMENT FACTORS* FOR SEEDING EXPERIMENTS

SEEDING MASS AND MODAL DIAMETER OF PARTICLE DISTRIBUTION	VISIBILITY AT TIME OF SECONDARY EXPANSION		MAXIMUM VISIBILITY IMPROVEMENT FACTOR
#2. 5g NaCl (4μ)	SEEDED CONTROL	210 FT 160	6.9
4. 10g NaCl (4μ)	SEEDED CONTROL	210 180	13.2
5. 2.5g NaCl (4μ)	SEEDED CONTROL	280 180	2.8
7. 10g NaCl (8μ)	SEEDED CONTROL	255 170	8.0
10. 10g UREA (CLUMPING)	SEEDED CONTROL	195 185	4.3
12. 10g UREA	SEEDED CONTROL	230 155	10.8
13. 5g UREA	SEEDED CONTROL	150 155	6.6
17. 5g NaCl (8μ)	SEEDED CONTROL	210 230	6.2
18. 125g NaCl RANGE(44μ-125μ)	SEEDED CONTROL	225 230	13.7

Table III

VISIBILITY IMPROVEMENT FACTORS* FOR SEQUENTIAL SEEDING EXPERIMENTS

SEEDING MASS AND MODAL DIAMETER OF NaCl PARTICLES	VISIBILITY AT TIME OF SECONDARY EXPANSION		VISIBILITY IMPROVEMENT FACTOR DUE TO 1st SEEDING	VISIBILITY IMPROVEMENT FACTOR DUE TO 2nd SEEDING
#15. 5g-5g NaCl (8μ)	SEEDED CONTROL	190 FT 230	2.5	10.3
23. 5g-5g NaCl (8μ)	SEEDED CONTROL	205 210	2.8	9.5
26. 5g-2.5g NaCl (LIGHT FOG)(8μ)	SEEDED CONTROL	670 685	7.4	15.8

* VISIBILITY IMPROVEMENT FACTOR IS DEFINED AS THE RATIO OF THE VISIBILITY OF THE SEEDED FOG TO THE VISIBILITY OF THE CONTROL FOG AT THE SAME TIME AFTER INITIATION OF THE EXPANSION.

We are continuing our analysis of data to determine, as in previous tests, the effect of seeding on drop-size distribution, liquid water content and drop concentration. Results of this analysis will be presented in a subsequent quarterly report.

D. Preparations for Field Tests.

Initial field tests of the proposed seeding concept will take place in late spring of 1968, provided the mobile seeding unit and particle disseminator are operational at that time.

The Trost jet mill, which will be used for particle dissemination, has been ordered and is expected at CAL by the latter part of January. The jet mill will be modified to act as a particle classifier; subsequent tests will be performed to determine optimum control settings, nucleus size distributions, and maximum particle dissemination rate.

The mobile test rig* has not yet been acquired but word regarding its availability is expected soon. Once acquired, the jet mill, duct work, propeller and feeder system will be installed on the flat-bed part of the rig. A small storage area from which seeding material can be passed to the feeder system will be installed on the mobile unit.

Instrumentation for monitoring the effects of seeding is being designed and will be built in time for spring tests.

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* Developed at CAL for the Army Aviation Material Laboratory.

III. FUTURE PLANS

A.) Analyze data acquired from recent Ashford N. Y. laboratory seeding tests.

B.) Continue theoretical modeling of fog seeding and the preparation of computer programs to handle data inputs from seeding experiments.

C.) Continue preparations for large-scale seeding experiments.

REFERENCE

Kocmond, W. C. and J. E. Jiusto, 1967: Project Fog Drops, IV Annual Summary Report, Cornell Aeronautical Laboratory, Inc., Report Number RM-1788-P-17.