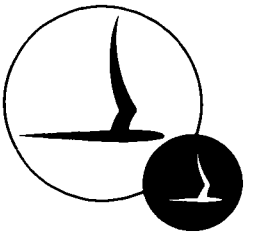

CORNELL AERONAUTICAL LABORATORY, INC.
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PROJECT FOG DROPS

INVESTIGATION OF WARM FOG PROPERTIES AND FOG MODIFICATION CONCEPTS

QUARTERLY PROGRESS REPORT

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PREPARED BY: Warren C. Kocmond
Warren C. Kocmond

AND James E. Jiusto
James E. Jiusto

(Principal Investigators)

APPROVED BY: R. J. Pilié
Roland J. Pilié, Asst. Head
Applied Physics Department

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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. The program to date has 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.

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

II. TECHNICAL DISCUSSION

A. Nuclei Classification Experiments

We have pointed out in previous reports the importance of using nuclei having the proper size distribution (4 to 10μ diameter) when preseeding radiation fog. In an attempt to obtain suitable nuclei, several manufacturers of commercially available particle classifiers were contacted for information on their equipment. After carefully analyzing the information available it was apparent that these classifiers could not remove particles of less than 2μ diameter with adequate efficiency. We therefore initiated a development program of our own.

During the past report period substantial progress in classifying nuclei was made. Three experimental techniques were examined; sieving, centrifugal separation and sedimentation. Of these the latter two show significant promise.

Our experience in using the electroformed sieves in the subsieve region (less than 44 μ) indicates that this technique, while sound, yields extremely small quantities of material and the classified salt badly agglomerates. *

The centrifugal classifier developed on this program is a modification of commercially available equipment and appears to be suitable for both classifying and disseminating salt particles of the proper size distribution. Prior to modification approximately one percent of the particle output (by number) was in the 4 to 10 micron range. After modification 50 to 60% of the particles were in this size range and 85 to 90% were in the 2 to 10 micron range. By removing a fraction of the small (submicron) particles before

*Sieving techniques have been developed which enable us to obtain salt particles of approximately 20 μ to 40 μ diameter - a size range suitable for testing the fog dessication hypothesis also under consideration.

insertion of the salt into the classifier we have been able to improve efficiency so that 70 to 80% of the particles are in the 4 to 10μ range. Details of the method will be included in a later report.

B. Laboratory Experiments

In order to compare observations of visibility in seeded and unseeded fog with computed visibilities we have made provisions for measuring droplet size and concentration in our eight-foot tall fog chamber. Droplet concentrations are photographically recorded with a 35 mm camera viewing an intense ribbon of light at right angles. Observations of drop size and concentration are made by exposing gelatin coated slides in the fog. Measurements of light attenuation are simultaneously recorded with a transmissometer.

A series of experiments has been conducted to determine both drop sizes and concentration in seeded and unseeded fogs and to relate these measurements to observations of fog visibility. Results of these measurements have shown that a typically dense fog (1000 to 1500 feet visibility as measured by a transmissometer) consists of from 300 to 450 droplets cm^{-3}. After 10 minutes of "natural" fog formation, drop sizes were found to be 2μ to 5μ diameter. These values of drop size and concentration were consistent with the measured attenuation.

In the seeded fog cases droplet growth on natural nuclei was generally suppressed so that fewer dropls were observed for several minutes after seeding. Drop diameters usually ranged between 2μ and 25μ after five minutes of fog formation. After 10 minutes most of the larger drops had settled out of the chamber so that relatively few droplets were greater than about 10μ diameter. Larger drops, of course, would grow and persist if the residence times of the artificial nuclei (NaCl) in the saturated environment could be increased. (This will be achieved in the intermediate scale experiments planned in the large CAL test chamber at Ashford, N. Y. - see next section).

Some of the above observations are illustrated by the results of the following case. After flushing the test chamber with outside air for 30 seconds, a fog was allowed to form on the natural aerosol. Observations of droplet concentration were made as a function of time. Measurement of drop size were made upon completion of the experiment ($\sim$10 min) since drawing air from the chamber while fog is forming would alter the characteristics of the fog. Results of these observations indicated that after 5 minutes of formation

time, the natural fog consisted of about 140 droplets cm^{-3}. At the end of 10 minutes the number increased to about 420 cm^{-3}. Drop sizes averaged about 4μ in diameter. Assuming a droplet concentration of 400 cm^{-3} and a mean diameter of 4μ, the computed visibility in this fog is about 1200 ft, a value consistent with the transmission measurements.

A second air sample was then passed through the chamber together with artificial NaCl nuclei (see 3rd Annual Summary for a description of the seeding procedure). Observations of the droplet concentration in this case showed that after 5 minutes of fog formation only 15 nuclei cm^{-3} had grown to observable droplet sizes, a concentration almost 10 times less than in the unseeded fog. Droplet concentration slowly increased for the next several minutes until most of the droplets formed on artificial nuclei had settled out of the chamber; natural fog then began to form. After 10 minutes about 300 droplets cm^{-3} were observed. Since most of the hygroscopic nuclei had settled out of the chamber by this time, droplet sizes were predominantly less than 10μ diameter.

This trend of events demonstrates one concept we are trying to develop (i.e., to redistribute fog liquid water from a large number of small drops to a relatively few large drops).

C. Fog Simulation Facility

Initial tests were conducted at CAL's Ordnance Laboratory (Ashford, N. Y.) facility to determine whether it could be used for realistic fog simulation. The test chamber consists of an all-metal cylinder, 30 feet in diameter and 30 feet high. Numerous glass viewing ports, a circulating water spray, and a modest pressurization (positive and negative) capability are features of the chamber that make it appear attractive for fog work. Specifically the objectives of the one-day test were to answer the following questions:

1. Can fogs be formed in the chamber?
2. How persistent are they?
3. What are typical fog drop sizes and concentrations that result?
4. Are such fogs (microphysical characteristics) representative of those occurring in nature?

The data that were obtained are presently being analyzed. It can be stated from initial observations that suitably persistent, representative fog can be formed readily. As a result we are proceeding with appropriate full scale instrumentation of the chamber in anticipation of fog formation and modification experiments during the next report period.

D. Investigation of Atmospheric Nuclei at Subsaturated Humidities:

It is well known that certain nuclei in the atmosphere are sufficiently large and hygroscopic to produce fog droplets several microns in diameter at humidities below 100%. We have suggested that a thermal gradient diffusion chamber, employing liquids other than pure water, might provide readily variable, sub-saturation with respect to water. Such a unit could activate hygroscopic nuclei with given relative humidity thresholds less than 100% thereby depicting those nuclei instrumental in haze and fog formation. A review of the idea and possible chamber designs indicates that this "haze chamber" (1) can be readily constructed, (2) inherently provides information on the important giant nucleus concentrations, and (3) can be operated to yield slight supersaturations as well.

1. Haze Chamber Design

a. General Principles

Aqueous salt solutions are commonly used to create fixed sub-saturated conditions in a confined environment. For ideal solutions, Raoult's Law states that the partial vapor pressure of a solution component (A) is proportional to the mole fraction of A in solution:

$$P_A = P_A^\circ X_A \quad or \quad P_A / P_A^\circ = \frac{R.H.}{100} = X_A \tag{1}$$

where $X_A = n_A / (n_A + n_B)$, and (2)

P_A is the partial pressure of component A (water)

P_A° is the saturated vapor pressure of pure liquid A

X_A is the mole fraction of A

n_A, n_B are the number of moles of A (water) and B (salt) respectively.

Note that P_A / P_A° is equivalent in this case to the relative humidity.

The relative vapor pressure lowering ΔP can be expressed as:

$$\Delta P / P_A^\circ = 1 - X_A = X_B \tag{3}$$

where X_B is the mole fraction of B (salt) present. Maximum vapor pressure lowering, corresponding to a saturated solution, varies with the salt chosen. Some examples of equilibrium humidities are given in Table I. These humidities vary somewhat with temperature; for NaCl, the variation is only 1% over a 40° temperature range (0 - 40°C).

Table I

Relative Humidity over Saturated Aqueous Salt Solutions

(Temperature = 20°C)	
LiCl	15%
$CaCl_2 \cdot 6H_2O$	32
NaCl	75
$(NH_4)_2\ SO_4$	81
KNO_3	90
$CaSO_4 \cdot H_2O$	98

Rather than using a number of separate salt solutions to simulate a range of humidity conditions, we decided to achieve the same versatility with a single solution. This can be done with a modified thermal-gradient diffusion chamber whose upper and lower water reservoirs are replaced with salt solutions. It is essential to use identical solutions in both reservoirs and convenient if they are saturated. Figure 1 illustrates the governing principle involved.

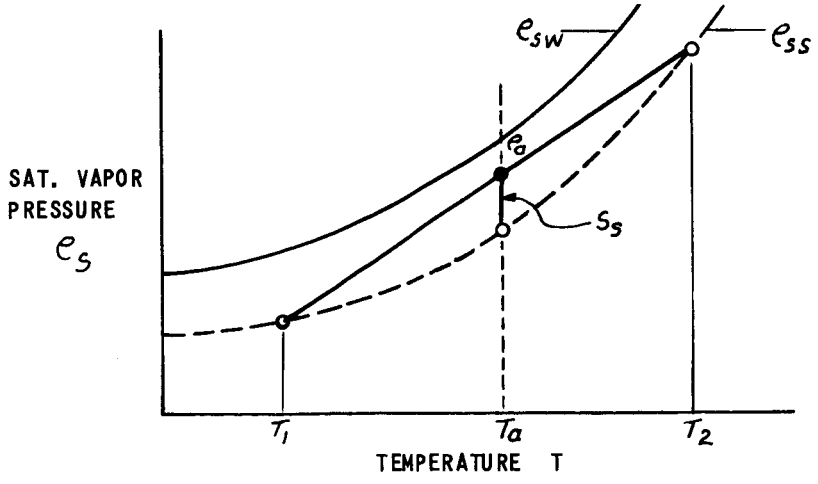

Figure 1 PHASE DIAGRAM OF HAZE CHAMBER PRINCIPLE

The solid and dashed curves represent saturation vapor pressure with respect to water and aqueous salt solution respectively. For a saturated NaCl solution, $e_{ss} = 0.75\, e_{sw}$. In this case with no temperature difference between reservoirs, relative humidity in the chamber is obviously 75%. As $\Delta T = T_2 - T_1$ increases, higher humidities are achieved as represented by the straight line in accordance with the following:

$$RH = 75 + 100\, S_s \tag{4}$$

$$S_s = \frac{e_a(T_a) - e_{ss}(T_a)}{e_{sw}(T_a)} \tag{5}$$

The partial pressure of the salt in solution is negligibly small, which otherwise would complicate expressions (4) and (5). Laboratory evaporation tests with NaCl solution were run to confirm this.

b. Chamber Humidity vs. Temperature Difference

For our initial tests we chose to use a saturated NaCl solution since it had the advantages of non-toxicity, well documented chemical characteristics, a base humidity (75%) of significance in atmospheric haze problems, and a near-constant temperature vs. relative humidity relationship.

Consequently, values of haze chamber humidity (maximum) as a function of temperature difference between reservoirs (NaCl solution) were computed. The results are shown in Table II.

Table II

Approximate Value of Maximum R.H. vs. ΔT in Haze Chamber

Upper reservoir temp. = 30°C (constant)

ΔT	R.H.
0°C	75%
2	75.2
4	75.4
6	76.0
8	76.7
10	77.7
12	79.4
14	80.8
16	82.8
18	85.2
20	87.8
22	90.7
24	94.1
26	97.8
28	102.1
30	106.6

In order to cover the relative humidity range from 75-100%, temperature differences of up to 27°C were necessary; note that temperature differences exceeding this value produce supersaturated conditions. The broad temperature range involved required heating of the upper reservoir, in addition to cooling the lower. We discovered that below 90% RH very few nuclei were observable within the sensitive vaolume of the diffusion chamber. It should be emphasized that droplet growth at sub-saturated conditions is highly restrictive; that obviously no growth can occur with nonhygroscopic nuclei and that most activated hygroscopic nuclei will do little more than deliquesce (approximately double in size). Hence it remains to be determined what portion of the nuclei spectrum we are detecting with the

existing optics system. From the results of our initial tests there appears to be little virtue in operating at humidities as low as 75%. Some examples of droplet growth on NaCl nuclei of given size and equilibrium humidity are indicated in Table III.

Table III

Droplet Growth on NaCl Nuclei at
Relative Humidities of 100, 99, and 95%

Initial Radius r	Initial Nucleus Mass	—Final Drop Size and Growth Time— 100% R.H. r_f	t	99% R.H. r_f	t	95% R.H. r_f	t
0.05μ	10^{-15} g	0.32μ	.09 sec	0.20μ	.01 sec	0.16μ	< .01 sec
0.10	10^{-14}	1.00	2.8	0.50	.44	0.25	< .01
0.22	10^{-13}	3.18	91.5	1.00	.26	0.63	.04
0.48	10^{-12}	10.00	2776	2.51	6.7	1.58	.11
1.03	10^{-11}	31.70	1494 min	5.02	10.8	2.52	.13
2.23	10^{-10}	100.5	804 hr	12.7	122	7.98	97
				(10.1)	(23)	(6.3)	(3.2)

It is probable that with this chamber we will be able to detect nearly all the "giant" nuclei (i.e. $r > 1.0\mu$ radius), some of the "large" nuclei ($0.1 \leq r \leq 1.0\mu$, and virtually none of the "Aitken" nuclei ($r < 0.1\mu$). This built in discrimination is desirable since the relative importance of these nucleus size classes in cloud development follows a similar trend, i.e., decreasing importance with decreasing size.

Since the concentration of particles in the atmosphere decreases as the inverse square or cube of particle size, it may well be necessary to increase the sampling volume of the present optics system. Also, the vertical relative humidity gradient in this haze chamber considerably exceeds that in the cloud chamber so that the narrow dimension of the sample volume probably should be algined in the vertical. Alternately, the use of

a small sample volume and automatic scanning might be explored.

2. Conclusions

a. The haze-chamber concept, incorporating saline solutions and the thermal diffusion principle, appears valid.

b. Initial tests indicate that very few nuclei are observable below 90% RH but that routine measurements of "giant" hygroscopic nuclei can be obtained by this method.

c. The upper and lower reservoirs should contain identical saline solutions and be saturated. We will experiment with various salts differing in equilibrium relative humidity at saturation.

d. In essence the chamber is a detector of hygroscopic, giant (some large) nuclei. Non hygroscopic nuclei and Aitken nuclei are discriminated against.

III. OUTLINE OF FUTURE PLANS

1. Prepare CAL Ordnance Laboratory for fog seeding experiments of an intermediate-scale. Items of importance will be:

a. Determine most advantageous means of producing 'natural' fog within test chamber.

b. Instrument chamber for making measurements of fog droplet size and concentration, relative humidity, temperature and visibility in seeded and unseeded fogs.

2. Complete testing of haze chamber concept and construct an operational chamber for use on a routine basis.

3. Continue daily measurements of cloud and fog nucleus concentrations.

4. Conduct laboratory experiments using improved nucleus production and dissemination techniques and, as a result of these improvements, re-examine potential fog dessication methods.