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PROJECT FOG DROPS

INVESTIGATION OF WARM FOG PROPERTIES AND FOG MODIFICATION CONCEPTS

QUARTERLY PROGRESS REPORT
for the period ending 3/31/67

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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 second quarter of the fourth contract year. Plans for the next quarter are outlined.

II. TECHNICAL DISCUSSION

A. Fog Seeding Experiments of an Intermediate Scale - Ashford, N.Y.

A primary goal of this years warm fog research is to test and evaluate promising fog seeding concepts in the 750 m^3 chamber at the CAL Ordnance Laboratory, Ashford, N.Y. The preseeding concept described in Report No. RM-1788-P-13 and tested on a small scale in the laboratory has served as a focal point of these experiments. Because of our recent success in developing a centrifugal classifier for use in seeding experiments we have decided to re-examine potential fog desiccation methods as well. Formerly we were hesitant to experiment with desiccation techniques because of the unrealistic payloads required to clear a zone of foggy air over a runway. Improved means of classifying and disseminating hygroscopic particles of the proper size,* however has warranted a re-evaluation of this concept. To highlight the differences between the two approaches under consideration a brief review of both concepts is given below.

1. Preseeding Concept

Our thinking relative to fog dissipation has centered around a seeding concept in which large hygroscopic nuclei are used to prevent dense natural fog from forming. We have hypothesized that if the fog can be made to consist of a relatively few large drops rather than the high concentrations of small drops that normally occur, that visibility through fog might be improved. Calculations indicate that for a constant liquid water content, visibility improvements as great as a factor of five might be achieved by preseeding an atmosphere

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*See Appendix A for a description of the particle classifier and dissemination used for seeding experiments.

in which fog would form. Extensive laboratory experiments in our eight-foot tall fog chamber showed that improvements greater than a factor of two were not uncommon. To determine more precisely the effects of preseeding on natural fog formation we are testing this concept in the 750 m^3 Ordnance Laboratory.

2. Desiccation Concept

An alternate approach, though by no means an original one, is to seed the atmosphere with hygroscopic particles after the fog forms in order to lower the relative humidity and cause evaporation of natural fog droplets. Limited success of this concept has been due, in part, to an inability to disperse hygroscopic particles of the proper size into the atmosphere. Obviously if submicron particles are used for seeding, the fog liquid water will be redistributed in such a way as to produce increased scattered light and even poorer visibility. On the other hand if excessively large particles are introduced into the fog the scheme becomes too inefficient. The crux question remains: Is the amount of material required for optimum desiccation still prohibitive? Our initial experiments indicate that perhaps less material may be required than originally thought necessary.

Theoretical considerations

In order to make estimates of the salt mass requirement for desiccation experiments it was necessary to derive expressions for the size achieved by giant hygroscopic nuclei after falling through a given depth of fog and the time required for the growth and the fallout of droplets. Calculations were made to determine the amount of water extracted from the fog per giant NaCl nucleus as well as the total concentration and mass of salt necessary to clear the fog.

For the Ashford seeding experiments, in which the chamber is 10 meters tall, the expressions for drop radius and residence time are:*

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*See Appendix B for derivation of equations (1) and (2).

$$r_H = 490 (m_s)^{1/7} \qquad (1)$$

$$t_H = 1.11 \times 10^{-14} r_H 5/m_s \qquad (2)$$

where r_H = final drop radius after falling 10 meters
m_s = mass of hygroscopic nucleus
t_H = fall time

The above expressions relate to a constant relative humidity of 100%. In reality, as the salt particles dessicate the environment, the relative humidity will decrease so that drop growth rates will also decrease. Particle residence time however will substantially increase.

To obtain a bound on the salt requirement under these more involved conditions, we considered the final situation where relative humidity was reduced to equilibrium values of 99% and 95%. Details of the calculations are presented in Appendix B. Results are presented in Table 1. It is apparent from the data in Table I that 2 to 10μ radius NaCl nuclei are desirable; 5μ radius particles appear optimum for the Ashford configuration (750 m^{-3}) in which case 15-75 gm of salt (depending on equilibrium RH desired) are required per seeding. For out initial experiments 30 gm of salt was used.

3. Test Chamber Instrumentation

To evaluate 'natural' and seeded fog characteristics within the 750 m^3 chamber, instrumentation has been installed for measuring drop size distribution, temperature, relative humidity and visibility. Provisions for seeding-apparatus (centrifugal classifier described in Appendix A and dry nitrogen tank) have been made at the top of the chamber so that seeding of natural fogs can be simulated. Other support equipment includes a manometer, communication appartus, rate of climb meter and chart recorders. Several viewing ports are available for observing fog within the chamber.

Table I Fog Seeding in Ashford Facility (Equilibrium R.H. = 99% and 95%)

	Equilib. Drop Size		Final Size		Fall Time		Salt Conc.		Salt Mass	
	r_E	r_E	r_H	r_H	t_H	t_H	(cm^{-3})		($750\ m^{-3}$)	
r_i (ms)	(99%)	(95%)	(99%)	(95%)	(99)	(95%)	(99%)	(95%)	(99)	(95)
47.8 (10^{-6})	240 μ	140 μ	60 μ	60 μ	20 sec	40 sec	2.5	2.5	1900 g	1900 g
22.4 (10^{-7})	126	66	45	40	40	80	3.5	5	260	380
10.0 (10^{-8})	50	31	30	20	60	120	10	35	75	260
4.78 (10^{-9})	24	12.5	22	12.5E	170	290	20	100	15	75
2.24 (10^{-10})	11.5	6.5	12.5E*	6.5E	340	710	110	750	11	56
1.0 (10^{-11})	5	3	5E	3E	1700	5000	1700	10,000	12	75
0.48 (10^{12})	2.5	1.5	2.5E	1.5E	6700	20,000	14,000	62,000	11	46

*E indicates equilibrium size has been achieved.

4. Results of Preliminary Seeding Experiments

As previously discussed two types of seeding experiments are currently being evaluated:

(1) Preseeding the atmosphere with hygroscopic nuclei to inhibit natural fog formation.

(2) Seeding a foggy atmosphere with large hygroscopic nuclei to lower the relative humidity and cause dissipation of the existing natural fog, i.e., desiccation.

Producing dense 'natural' fog for desiccation experiments proved to be a relatively simple matter. The 750 m^3 metal chamber has the capability of modest overpressurization so that expansion of nearly saturated air readily produces dense fog. The procedure for forming fogs by this method is as follows: (1) the chamber walls are first sprayed with 100 gallons of water - a rotating spray nozzle within the chamber is used for this purpose, (2) outside air is then passed through the chamber for several minutes to provide natural nuclei on which fog can form. A large circulating fan is used to mix the air within the chamber, (3) the chamber is then sealed and the atmosphere within the chamber is overpressurized by about one inch of Hg., (4) relative humidity is allowed to increase to about 95%, (5) a sudden nearly adiabatic expansion is made - expansional cooling of the moist air within the chamber quickly produces supersaturation and fog forms.

Fogs produced in this manner were consistently found to have a visual range of less than 100 ft; less dense fogs could easily be formed by smaller expansions. The drop size distributions in fogs produced in that manner were found to be similar to those in dense radiation fog. Fog liquid water was probably somewhat higher in the artificially produced fogs than normally found in radiation fog.

Producing fogs for preseeding experiments proved to be more difficult. The fact that we wanted to form fogs in a manner consistent with natural fog formation (i.e. slow cooling rates) restricted our technique somewhat. The actual procedure for producing control fogs prior to preseeding was the same as the first four steps used for desiccation experiments. Instead of a sudden expansion, however, the moist air within the chamber was allowed to expand slowly and come to ambient pressure. In the preliminary experiments conducted to date we selected an expansion rate which, upon data analysis, we learned was causing a cooling rate of 12°C/hr. This of course is significantly greater than the cooling rates found during natural radiation fog formation. In future experiments expansion rates will be selected to produce more realistic cooling rates.

a. Preseeding trials

For preseeding experiments, seeding had to be accomplished before overpressurizing the chamber (i.e., before step 3). The large circulating fan was left on during **each experiment** in order to raise the humidity in the chamber more quickly. (We later discovered that leaving the fan on probably caused rather rapid impaction of the NaCl nuclei on the chamber walls.) After the relative humidity had risen to 95% a slow expansion was initiated to produce cooling of the moist air. Approximately 10 minutes elapsed from start of seeding to start of expansion. In these preliminary trials little difference in the visibility of seeded and unseeded fogs was noted. Gelatin coated glass slides placed in the chamber during the experiment (but not studied until the first series of experiments had been completed) showed that by the time the expansion was started nearly all of the artificial nuclei had fallen out of the atmosphere.

We have carefully reviewed these initial fundings (4 days of experiments) and have devised alternate means for producing natural fog for future preseeding experiments. One of the methods involves cooling the moist air by expansion only as long as necessary to initiate fog formation. Once the fog begins to form reduced cooling rates will be used to allow fog formation to proceed. In this way excessive cooling rates can hopefully be avoided and more realistic conditions of fog formation can be met. An alternate approach might be to create a thermal gradient within the chamber by flooding the floor of the chamber with a layer of very cold water (~5°C). An effect similar to that which takes place in the thermal diffusion chamber can be expected to occur - the obvious objection is that unrealistically high supersaturation would prevail very near the cold water surface.

The aforementioned techniques can easily be implemented at the Ashford Facility. The wide variety of methods that can be used for making natural fog make this facility an extremely useful one for testing seeding concepts. Additional preseeding experiments are planned during the next several weeks

b. Desiccation trials

For desiccation experiments no restriction on cooling rates was necessary since seeding was accomplished after the fog was formed. Before conducting seeding experiments control fogs were produced for comparison with seeded fog. Seeding of the foggy air was initiated shortly after completing a rapid expansion (i.e. while the fog was still very dense as well as persistent). Approximately 30 gm of material were used per experiment. To date only two full scale desiccation experiments have been attempted. In both cases, dramatic improvement in fog visibility resulted shortly after seeding.

The trend of events for seeded and unseeded fogs is illustrated in Figures 1, 2, and 3. Figure 1 shows visibility as a function of time after fog formation for a seeded and an unseeded fog. Figures 2 and 3 show the measured drop size distributions for these fogs at selected times.

Note in Figure 1 that after seeding is completed the visibility in the seeded fog improves rapidly from ~ 500 ft to 3600 ft, then levels off for several minutes. Our interpretation of the sequence of events in this experiment is as follows. After seeding, rapid growth on large hygroscopic nuclei takes place. This growth reduces the vapor pressure in the surrounding air which in turn causes evaporation of the natural fog drops. As the droplets evaporate, growth on the large hygroscopic nuclei continues until an equilibrium droplet size distribution is achieved. The equilibrium size of each solution drop is characterized by the relative humidity of the environment and the original mass and hygroscopicity of the nucleus.

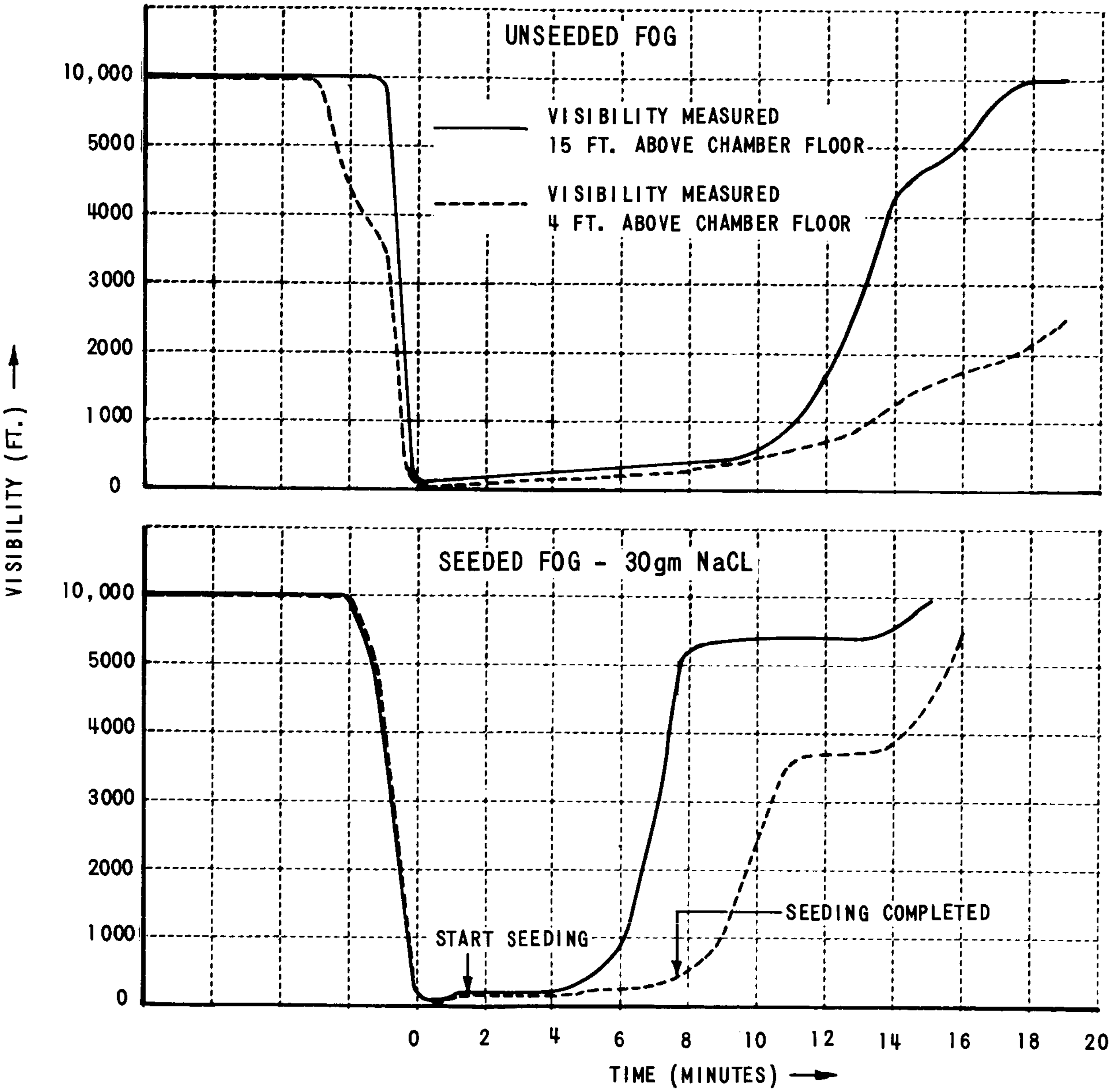

Figure 1 VISIBILITY AS A FUNCTION OF TIME FOR A SEEDED AND A UNSEEDED FOG

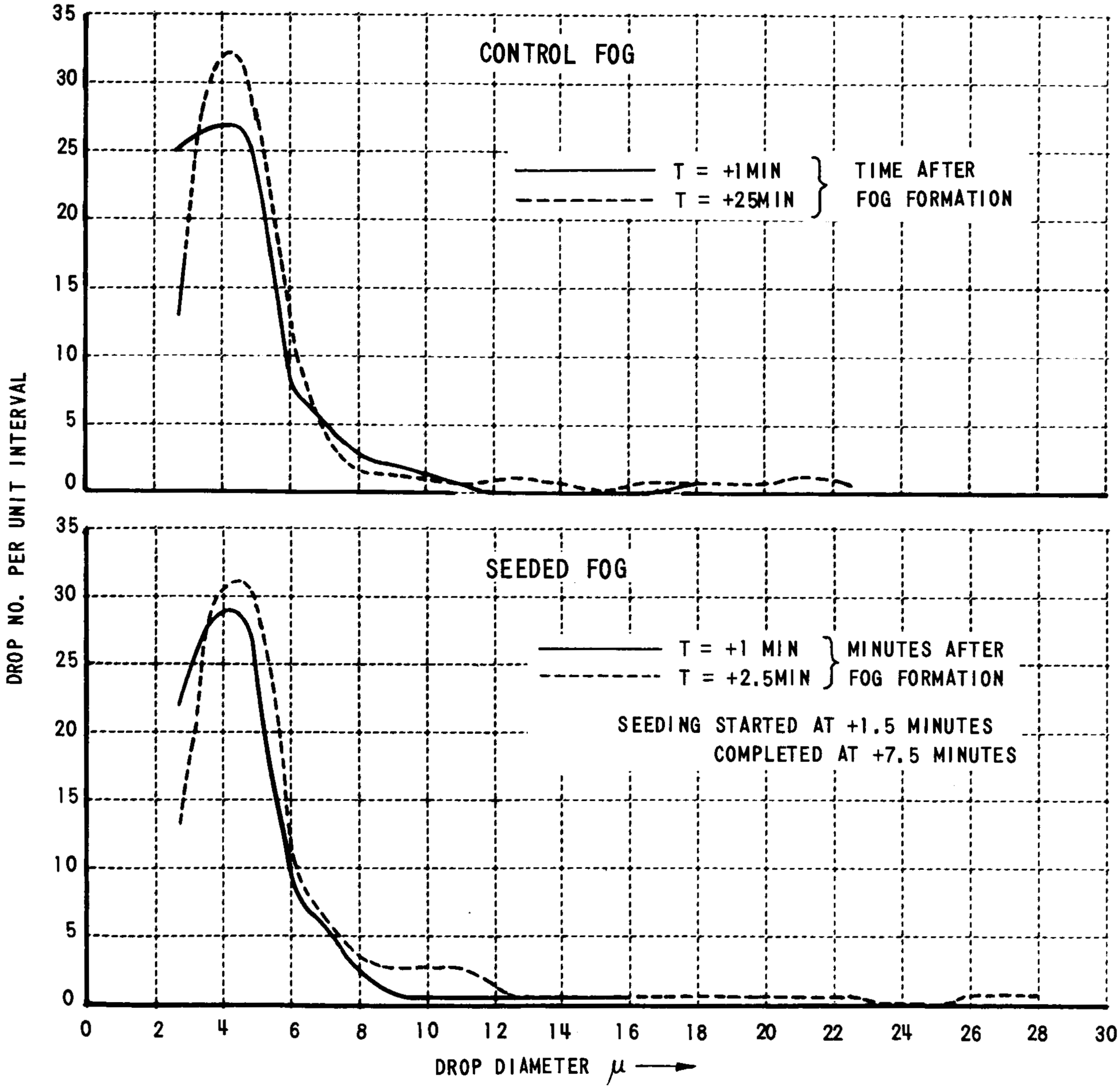

Figure 2 DROP SIZE SPECTRA FOR SEEDED AND UNSEEDED FOGS

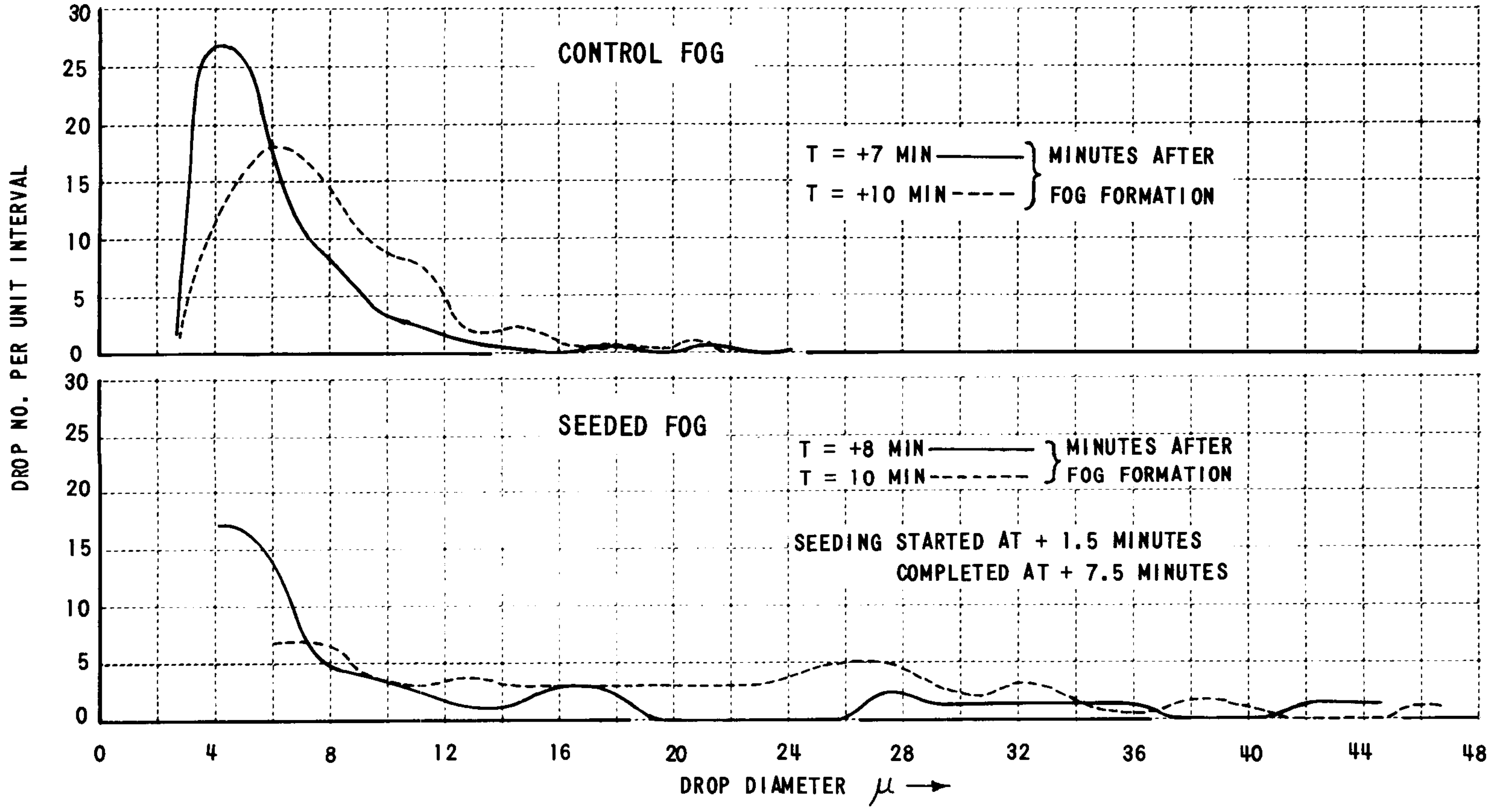

Figure 3 DROP-SIZE SPECTRA FOR SEEDED AND UNSEEDED FOGS

Visibility in the fog was improved because of two processes related to the net change in drop size distribution that occurred. Preliminary calculations show that the sizes achieved by droplets growing on the larger artificial nuclei were sufficient to cause fall out of some water from the fog between the time that NaCl nuclei were introduced into the fog and the time that visibility improvements were noted, which was about three minutes. These calculations were verified by the drop sizes observed on gelatin coated slides placed on the chamber floor during the experiments. In addition, the change in drop size distribution from many small droplets to a few large droplets caused an improvement in visibility in the same manner as we are attempting to produce in the preseeding experiments.

Figure 2 shows that the drop size distributions in the two fogs prior to seeding were nearly the same. Figure 3 illustrates the rather pronounced shift toward larger drop sizes that is caused by seeding. The shift in drop sizes is also illustrated by the photomicrographs in Figures 4a and 4b. These photographs show droplet impressions on gelatin coated slides taken 10 minutes after fog formation in seeded and unseeded fogs. The absence of small drops in the seeded fog is striking.

During the coming weeks additional experiments will be required to evaluate the preseeding and desiccation concepts. Efforts will be made to compute fog liquid water and drop concentration in seeded and unseeded fogs. Observations in fogs of varying density will be made and mass requirements of seeding material will carefully be assessed. Of particular importance will be the determination of minimum amounts of material required to achieve the required clearing objective. At that time recommendations as to the feasibility of full-scale fog experiments with hygroscopic materials can be given.

B. Investigation of Atmospheric Nuclei at Subsaturated Humidities

We have previously suggested that certain hygroscopic nuclei instrumental in haze and fog formation might be studied using a modified thermal gradient diffusion chamber (i.e. 'haze' chamber) in which controlled relative humidities smaller than 100% could be maintained. During the past reporting period we

Figure 4a DROPLET IMPRESSIONS TAKEN IN UNSEEDED FOG 10 MINUTES AFTER FOG FORMATION

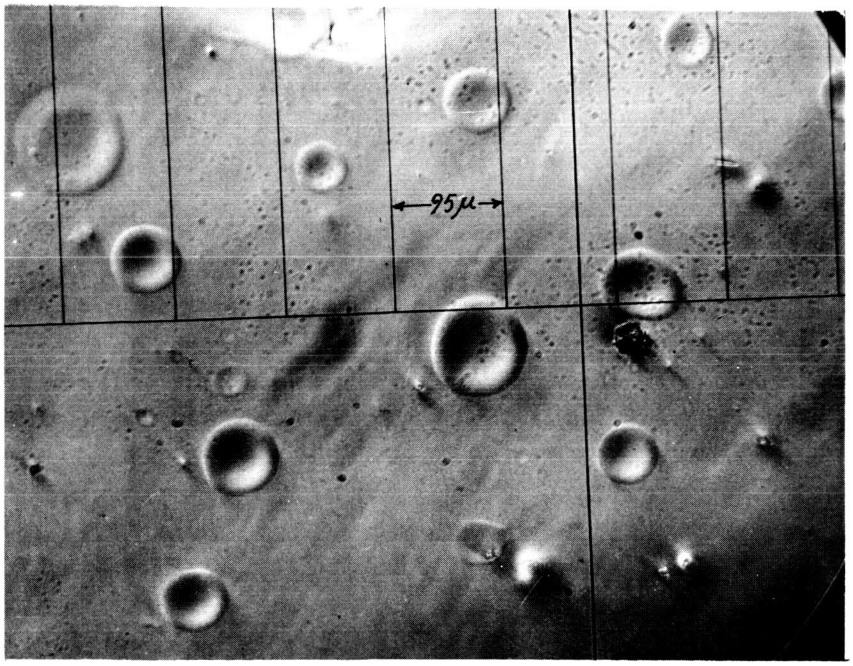

Figure 4b DROPLET IMPRESSIONS TAKEN IN SEEDED FOG 10 MINUTES AFTER FOG FORMATION*

* VERY SMALL AND SOMEWHAT FUZZY IMPRESSIONS SEEN IN IDENTICAL POSITIONS ON BOTH SLIDES ARE DUE TO FOREIGN MATTER ON THE RETICULE

demonstrated the feasibility of such studies experimentally and have designed and nearly completed construction of a haze chamber for making the required observations on a routine basis.

The basic instrument is similar to the thermal diffusion chamber we now use for making cloud nucleus observations. Major differences are:

1) the use of saturated KNO_3 solutions for the upper and lower water reservoirs. Numerous measurements made during our preliminary experiments suggest that very few nuclei grow to observable droplets at relative humidities below 95%. The equilibrium R.H. of saturated KNO_3 solutions (95%) therefore appears best suited to our measurements.

2) a larger sensitive volume to improve statistics of measurements. The sensitive volume of the haze chamber is 0.25 cm^3 a volume four times greater than that used in our present system.

Other features of the haze chamber are essentially the same as those used for the thermal diffusion chamber (i.e., thermoelectric cooling, mercury arc illumination, poloroid photographs of droplets).

It is expected that routine measurements of "giant" nuclei ($r > 1.0\mu$ radius) and some "large" nuclei ($0.1 < r < 1.0\mu$) can be made with this chamber. Observations of nucleus concentration as a function of relative humidity should begin within the next few weeks.

III. OUTLINE OF FUTURE PLANS

1. Continue testing the proposed fog seeding concepts at the CAL Ordnance Laboratory.

2. Based on the findings of item (1), make preliminary recommendations as to the feasibility of these concepts for large scale testing and initiate a study of suitable techniques for field experiments.

3. Continue measurements of cloud and fog nucleus concentrations and begin using the haze chamber on a routine basis for detecting nuclei active at subsaturated humidities.

APPENDIX A

Particle Classifier and Disseminator Used For Fog Seeding Experiments

The device used for classifying and disseminating nuclei in our experiments is a Trost Jet Mill* which has been substantially modified on this program. A cross sectional view of the jet mill is shown in Figure 1-A. Modifications made on the mill include exit port (P_2) and the urethane insert (U) shown in the figure.

1. Operation of Trost Jet Mill Prior to Modifications

During normal operation particles are fed through the material input and travel clockwise within the classification chamber about the collector port (P_1). Compressed air or bottled gas is used to drive the mill. The two opposing gas streams cause collision and fracturing of particles in the grinding chamber. Smaller particles are removed by the cyclone action of the gas escaping through P_1. Larger particles recycle within the classification chamber until additional collisions produce finer particle sizes. The process is repeated until all of the material introduced into the mill is exhausted to the collector. The mill when used as described above, is very effective in producing sub-micron sized particles.

2. Modified Jet Mill

To produce particles in the desired size range for seeding experiments (4-10μ)** the jet mill was modified so as to include a second exit port (P_2)

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* Manufactured by Helme Products, Inc., Helmetta, N.J.

** We have submitted a patent disclosure for the modifications made on this program.

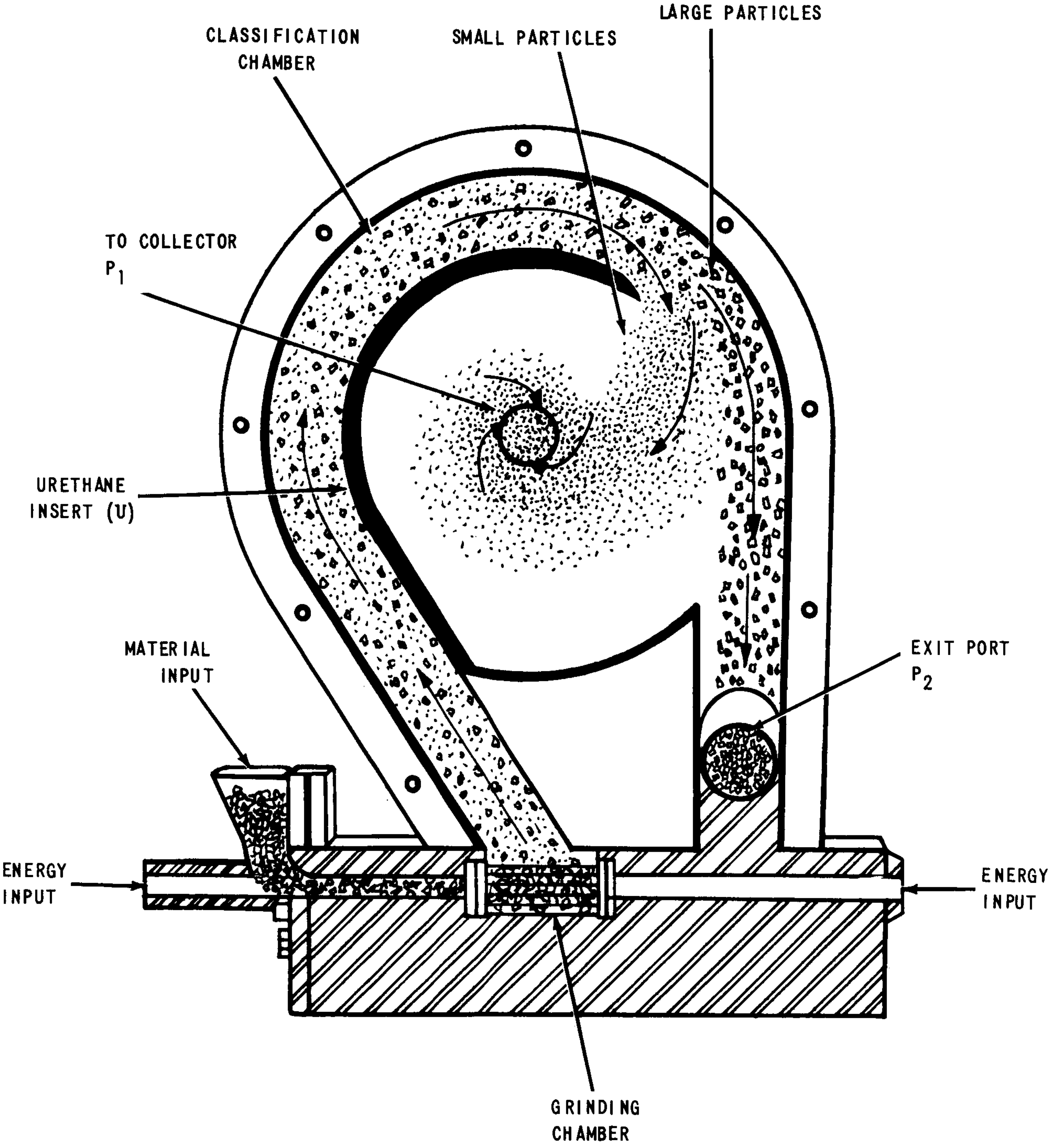

Figure 1-A TROST JET MILL WITH MODIFICATIONS

for particles. The additional port allows larger particles to be separated from the gas stream without repeated grindings, while the cyclone, or central port, is used to remove small particles in the gas stream. To further enhance particle separation a small urethane insert (U) has been installed in the classification chamber. The insert causes all incoming material to be guided about the periphery of the classification chamber until the particles approach port P_2. At that time, smaller particles having a high ratio of surface to mass, are removed by the cyclone action of the gas through P_1 and are collected in a "cyclone jar." Particles of intermediate size, which are still small enough to be undesirable, are prevented from re-entering the main particle stream by the urethane insert and are eventually drawn into P_1. Larger particles, considered desirable for seeding, are exhausted through port P_2. As a result of the aforementioned modifications we are able to produce particles in the 4-10μ size range with an efficiency of 70%, i.e. 70 percent of the particles by count are in the proper size range.

In actual operation of the mill, direct dissemination of dry salt particles into the atmosphere is possible. The modified jet mill, as described, is currently being used in our fog seeding experiments at the CAL Ordnance Laboratory, Ashford, N. Y.

APPENDIX B

Droplet Growth on Giant Salt Nuclei (Fog Desiccation Concept)

1. Theory

Calculation of droplet growth, fall distance and time relationships involve combining the three equations: Stokes terminal velocity of spheres, droplet growth by diffusion, velocity definition. (Symbols defined in Section 3 of this Appendix.)

velocity eqn. $h = vt$ (B-1)

differentiating (B-1), $dh = v\,dt + t\,dv$ (B-2)

Stokes eqn. $v = \frac{2}{9} r^2 g \frac{(\rho_0 - \rho_{air})}{\eta_{air}} \simeq \frac{2}{9} \frac{\rho_0 g}{\eta} r^2$ (B-3)

Diff. (B-3), $dv = \frac{4}{9} \frac{\rho_0 g}{\eta} r\,dr$ (B-4)

Drop growth eqn. $r \frac{dr}{dt} = G\left(S - \frac{a}{r} + \frac{b}{r^3}\right)$ (B-5)

For giant nuclei $\frac{a}{r} \ll \frac{b}{r^3}$ and assuming $S = 0$ (RH = 100%).

$$r \frac{dr}{dt} \simeq G \frac{b}{r^3} \quad or \tag{B-5a}$$

$$dt = \frac{r^4 dr}{Gb} \tag{B-6a}$$

Integrating (B-6a)

$$t = \frac{1}{5Gb}\left(r^5 - r_0^5\right) \quad \text{or} \quad t \simeq \frac{r^5}{5Gb} \tag{B-6b}$$

Substituting (B-4) and (B-6a) into (B-2),

$$dh = \frac{vr^4}{Gb}\,dr + \frac{4}{9}\,\frac{\rho_0 g}{\eta}\,t\,r\,dr \tag{B-7}$$

Substituting (B-3) for v and (B-6b) for t into (B-7)

$$dh = \frac{2}{9}\,\frac{\rho_0 g}{\eta G b}\,r^6\,dr + \frac{4\rho_0 g}{9\eta 5Gb}\left(r^6 - r r_0^5\right)dr \tag{B-7a}$$

Integrating (B-7a) over vertical depth H,

$$\int_0^H dh = \int_{r_0}^{r_H}\left(\frac{14}{45}\,\frac{\rho_0 g}{\eta G b}\,r^6\,dr - \frac{4}{45}\,\frac{\rho_0 g}{\eta G b}\,r r_0^5\,dr\right)$$

or

$$H = \frac{2}{45}\,\frac{\rho_0 g}{\eta G b}\left[r^7 - r_0^5 r^2\right]_{r_0}^{r_H}$$

$$H = \frac{2}{45}\,\frac{\rho_0 g}{\eta G b}\left(r_H^7 - r_0^5 r_H^2\right) \tag{B-8}$$

Since $r_0^5 r_H^2 << r_H^7$ after significant times,

$$H = \frac{2}{45}\,\frac{\rho_0 g}{\eta G b}\,r_H^7 \tag{B-9}$$

$$b = 4.3 i\, m_S / M \tag{B-10}$$

$$H = \frac{2}{45}\,\frac{\rho_0 g}{\eta G}\left(\frac{M}{4.3 i\, m_S}\right) r_H^7 \tag{B-11}$$

For NaCl, $i \simeq 2$, M = 58.5 and Eqn. (B-11) becomes ($b \simeq 0.147\, m_s$),

$$H = \frac{2}{45}\, \frac{\rho_0\, g\, r_H^7}{\eta G (0.147\, m_s)} \tag{B-12}$$

or

$$\boxed{H = 0.302\, \frac{\rho_0\, g}{\eta G\, m_s}\, r_H^{\,7}} \tag{B-13}$$

2. Numerical Calculations using Prior Expressions

$\rho_0 \simeq 1.1$ g m^{-3} (equiv. to drop = 2 nucleus dia.)

g = 980 cm sec^{-2}

T = 20°C

$G_{20°C}$ = 1.227×10^{-6} cm^2 sec^{-1}

$\eta_{20°C}$ = 1.82×10^{-4} g cm^{-1} sec^{-1}

H = 10 m = 10^3 cm (Ashford site height)

From Eqn. (B-13)

$$H = \frac{1.46 \times 10^{12}}{m_s}\, r_H^7$$

or

$$\underline{r_H = .0183\, (H\, m_s)^{1/7}}$$

For H = 10^3 cm $\qquad \underline{r_H = .0488\, (m_s)^{1/7}}$

Summary: For r_H in microns, H in cm, m_s in g and NaCl nuclei:

$$\boxed{\begin{aligned} r_H &= 183 (H\, m_s)^{1/7} && \text{(B-14a)} \\ r_H &= 490 (m_s)^{1/7} && \text{(B-14b)} \\ t_H &= 1.11 \times 10^{-14}\, r_H^{\,5} / m_s && \text{(B-14c)} \end{aligned}}$$

For the Ashford experiments (desiccation of fog), estimates can now be made of droplet sizes achieved for nuclei of given sizes and the total salt requirement. The seeding assumptions are as follows:

(a) Fog depth 10 m (height of facility)
(b) Temperature 20°C
(c) Saturation vapor density 18 g m^{-3}
(d) Water vapor to be absorbed (~ 95% RH objective) 1 g m^{-3}
(e) Salt injected at top of fog.

Using Eqns. (B-14b) and (B-14c), the final drop size and dwell time of the particle in the chamber can be calculated. The mass of water extracted from the fog per giant nucleus can then be determined, as well as the total concentration and mass of salt needed to fulfill the indicated clearing objective. The resulting estimates are shown in Table B-I of this appendix.

Note that the figures in Table B-I relate to a constant relative humidity of 100%. As the salt particles desiccate the environment and supersaturation decreases, drop growth rates will decrease and particle dwell time increases. Eqn. (B-5a) takes the form

$$r \frac{dr}{dt} = G\left(s + \frac{b}{r^3}\right) \qquad \text{(B-15)}$$

To obtain a bound on the salt requirement under these more involved conditions, we will consider only the final situation where s has attained given equilibrium values of -1 and -5% (RH = 99 and 95% respectively). Integrating Eqn. (B-15) leads to:

$$t = \frac{r^2}{5G}\left[(s+br^{-3})^{-1} + \frac{3}{8} s(s+br^{-3})^{-2} + \frac{9}{44} s^2(s+br^{-3})^{-3} + \frac{81}{616} s^3(s+br^{-3})^{-4} + \cdots\right] \qquad \text{(B-16)}$$

Applying this equation for the largest salt particles, a more rigorous numerical solution for the smaller salt particles (Eqn. B-5 previously programmed on an IBM computer) and approximating the average fall velocity of the growing droplets, the data in Table I of the text (page 5) were compiled.

Table B-1 Fog Seeding in Ahsford Facility ($T = 20^{\circ}C$, Fog Depth = 10m, Fog Volume = 750 m^3; Rel. Humidity = 100%)

Salt Particle Radius (mass)	Final Drop Size r_H	Fall Time t_H	Water per particle m_p *	Salt conc.	salt mass (750 m^3)
47.8μ (10^{-6}g)	68μ	15 sec	45×10^{-8} g	2.2 cm^{-3}	1670 g
22.4 (10^{-7})	49	30	44.4	2.3	170
10.0 (10^{-8})	35	60	18.8	5.3	40
4.78 (10^{-9})	25	110	7.1	14.0	10
2.24 (10^{-10})	18	210	2.7	37.3	3
1.0 (10^{-11})	13	410	1.0	99.0	0.75
0.48 (10^{-12})	9.5	860	0.28	357	0.25

*$m_p = \rho_0 \frac{4}{3} \pi r_H^3 - m_s$

Hence the theoretical salt requirement for our Ashford tests is bounded by the values presented in Table I of the text and Table B-1 of this Appendix. In brief, it is apparent that 2-10μ radius salt particles are desirable; 5μ radius particles appear optimum for the Ashford configuration in which case 10-75 g of salt are required per seeding.

3. Symbols

a	droplet curvature term (~0.33/T)
b	droplet solubility term
g	gravitational acceleration
G	thermodynamic term
h, H	height
i	Van't Hoff factor
m_s	mass of hygroscopic nucleus
M	moleculer weight of nucleus
r	droplet radius
r_o	initial drop radius
r_H	final drop radius after falling distance H
RH	relative humidity
S	supersaturation
t	time
t_H	time after fall distance H
T	temperature
v	velocity
ρ_o	density of drop
ρ_{air}	density of air
η	viscosity of air