and the orientation of the helices is preserved (*16*). The exact nature of the amplitude variation (Fig. 2) is, however, not quite clear at present. Measurements of the unresolved spectrum with oriented DNA containing D_2O have given greatly altered spectra with indication of partly resolved hyperfine structure; a detailed study will be helpful for the characterization of the primary radicals.

The spectra of dry oriented DNA at room temperature (Fig. 3C) differ from those reported by Elliott and Wyard (*17*). They studied dry, oriented calf-thymus DNA fibers which were prepared by drawing at 66 percent relative humidity and wound on a quartz plate which could be rotated and moved vertically in an ESR quartz cell (*18*). After x-irradiation in dry nitrogen at room temperature in the upper part of the cell, the quartz plate with sample was transferred to the lower part of the cell which was placed in the ESR cavity. The reported spectra were much narrower than ours (4 gauss rather than approximately 24 gauss), exhibited a lower amount of fine structure, and showed a great *g*-value displacement in a direction opposite to that of our spectra. For unoriented DNA, however, they reported a thymine-like spectrum. Elliott pointed out some drawbacks with the quartz-plate holder (*18*) which might explain part of the differences between their results and ours. However, the disturbance from radicals formed in the quartz plate and the influence of the quartz plate on cavity-Q (quality factor) and frequency might be of greater importance, but these possible sources of error were not discussed by Elliott and Wyard (*17*). Gamma-irradiation in dry nitrogen at room temperature of one of our extensively dried, oriented sodium DNA samples gave spectra identical to those of Fig. 3C.

Our measurements show that the ESR signals from moist, oriented DNA, which was γ-irradiated and studied at low temperature, exhibit a strong angular dependence. Use of highly oriented DNA seems therefore to offer excellent opportunities for identifying radicals formed or annihilated when the temperature and water content are varied (*5, 8*). A very promising extension is suggested by the excellent work by Pershan *et al.* (*10*) on ultraviolet-irradiated DNA. Their measurements at various humidities and annealing temperatures indicated that at least five different radicals can be formed in this irradiated DNA, but only the thymine radical was identified. The use of oriented DNA possibly could facilitate the identification of the other radicals. Measurements are being made on oriented DNA samples with added paramagnetic ions (*19*) and on complexes of oriented DNA and substances such as polyaromatic dyes (*20*).

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11 July 1967

Warm Fog Suppression in Large-Scale Laboratory Experiments

Abstract. *Visibility in warm fog produced in a 600-cubic-meter chamber was increased by factors of 3 to 10 by seeding with carefully sized sodium chloride particles. As little as 1.7 milligrams of salt per cubic meter was effective. Extrapolation of these results indicates that clearing a suitable landing zone for aircraft would not involve prohibitive amounts of seeding material.*

Recent experiments in a 600-m^3 cloud chamber have demonstrated that visibility in warm fog can be improved by a factor of up to 10 by seeding with NaCl particles of carefully controlled size distribution. Previous investigations, notably the classic work of Houghton and Radford (*1*), were aimed at desiccating the atmosphere to substantially less than 100 percent relative humidity by causing condensation (and subsequent precipitation) of water on large saline droplets introduced into the atmosphere. The principal goals of our experiments were (i) to modify the drop size distribution of the fog in such a way as to reduce the Mie scattering coefficient and hence improve the visibility without necessarily altering the liquid water content, and (ii) to determine the minimum amount of dry salt particles of prescribed sizes that could significantly alter laboratory fogs.

Improved visibility results from modification of the drop size distribution in fog from the normal large number of small droplets to a few large droplets containing about the same liquid water. When a few suitable hygroscopic nuclei per cubic centimeter are introduced into a fog they immediately deliquesce into solution droplets. The equilibrium water vapor pressure over the growing solution drops is lower than saturation relative to pure water. If the concentration of artificial nuclei is sufficient to cause the average relative humidity of the treated region to fall only a fraction of a percent, some desired redistribution of water is accomplished and visibility improved.

Our calculations based on seeding only the lowest 100 m of fog (which would apply to the airport situation) indicated that the most effective NaCl nuclei sizes are between 4 and 10 μ in diameter. Much smaller particles would not grow to sizes significantly larger than natural droplets, while larger particles would fall out of the fog before condensing sufficient water to become "dilute" solution droplets. Approximately 80 percent of the particles were between 2 and 10 μ in diameter; 65 percent were between 4 and 10 μ. The mode of the distribution was consistently between 4 and 5 μ.

The experiments were conducted in a cylindrical chamber 30 feet (9 m) in diameter by 30 feet high. The chamber could be either pressurized or evacuated to approximately 20 cm of water at controlled rates. Fog was formed on natural nuclei existing in the rural atmosphere that was drawn into the chamber after the walls had been thoroughly wet. The chamber was pressurized, and after the internal temperature and humidity had been permitted to approach equilibrium with the wet walls, the chamber was vented to the atmosphere in a controlled manner. The near adiabatic expansion produced the fog. Visibility was determined from measurements made with a transmissometer having a 60-foot path length through the fog. Temperature (approximately 24°C) and humidity measurements, Aitken nuclei counts, and droplet replicas were made by an observer who was inside the chamber.

Ten experiments were conducted. Run (*a*) in Fig. 1 is typical of experiments in which the control fog was formed and allowed to dissipate naturally. After wetting of the walls and flushing of the chamber with outside air, a new fog was formed and seeded. The seeding rate for the case shown was 4 mg/m^3 (approximately 4 ppm of treated air; 1.7 mg/m^3 took longer; and 0.8 mg/m^3 was ineffective).

A comparison of computed and measured Mie scattered coefficients obtained from the drop size distribution and transmissometer data permits calculations of droplet concentration and liquid water content. Such an analysis of data obtained at time (t) = 15 minutes indicates that 70 percent of the visibility improvements of the seeded fog over the control fog was attributable to modification of the drop size distribution and 30 percent to increased precipitation associated with fallout of saline droplets formed on the largest nuclei introduced.

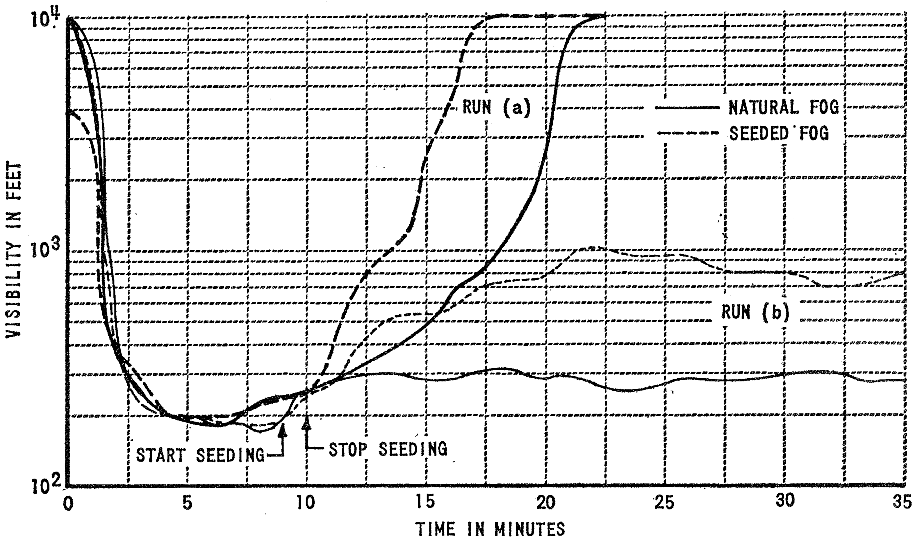

Fig. 1. Visibility improvement in warm fog due to seeding with salt particles 4 to 10 μ in diameter. Run (*a*): expansion terminated at 7 minutes, 4 mg/m^3 seeding rate; run (*b*): secondary expansion continued throughout experiment, 8 mg/m^3 seeding rate.

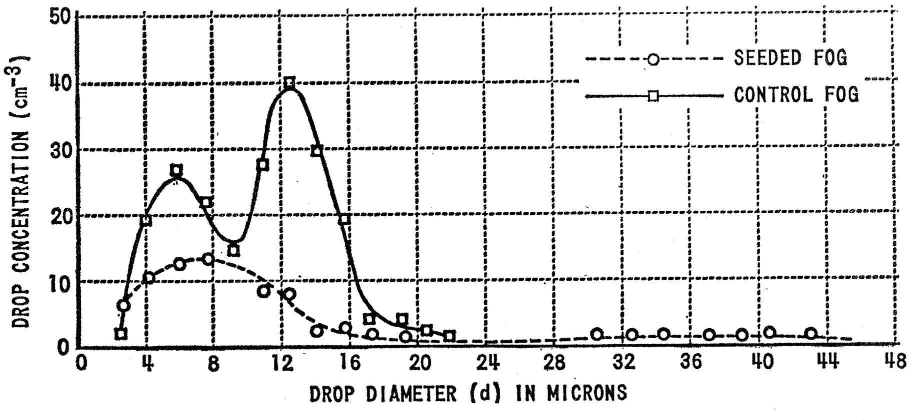

Fig. 2. Drop size distribution for seeded and control fog at +20 minutes. Occasional droplets of up to 56 μ in diameter were observed in the seeded fog.

Because in the preceding type of experiment the fogs being seeded were already dissipating, provisions were made to produce fogs of greater persistence. This was accomplished by initiating a secondary expansion at $t = 11$ minutes (3 minutes after terminating the primary expansion) and maintaining it through $t = 35$ minutes. Results are shown in run (*b*) of Fig. 1. Even though the secondary expansion caused additional cooling at a rate of 4°/hour, visibility was improved by a factor of 3. Eight milligrams of NaCl per cubic meter were used in this experiment. The change in drop size distribution that was produced by the seeding is illustrated in Fig. 2.

The visibility improvement from 200 to 300 feet in both fogs was due entirely to natural evaporation of droplets during the 3-minute interval between expansions. Additional cooling associated with the secondary expansion stimulated growth of new droplets in the control fog as well as continued growth of existing droplets. The size distribution obtained at the same time ($t = 20$ minutes) in the seeded fog shows no evidence of formation of new droplets and strong evidence of continued evaporation of existing droplets. In fact, less than 20 percent of the liquid water in the seeded fog (and more than 40 percent of the scattered light) was associated with drop sizes that were also present in the control fog. For the first 10 minutes after seeding, virtually all of the improvement in visibility was associated with the shift in the drop size distribution. Subsequent to that time precipitation played an increasingly important role in the improvement in relative visibility.

Extrapolation of these laboratory results to the far more difficult airport situation indicates that a landing zone 100 m high, 500 m wide, and 2 km long might be opened with 200 to 400 kg of properly sized salt particles.

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2. Supported by the Aeronautical Vehicles Division of NASA. Details of the experiments are in preparation for publication.

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