A NEW AIRBORNE ORGANIC ICE NUCLEI GENERATOR AND ITS TESTS IN SUMMERTIME CUMULI

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I. INTRODUCTION

In order to meet the need for effective, ecologically and operationally safe, and economical ice nuclei in weather modification, we have been developing practical smoke generators for three selected organic nucleants. They are 1,5-dihydroxynaphthalene (DN), metaldehyde (MA), and phloroglucinol (PG). In laboratory tests they have been shown to be as active as silver iodide. The characteristic features of these seeding agents are compared with those of AgI in Appendix A. In contrast with their numerous advantages, the only problem associated with the organic ice nuclei has been the generation of fine smoke particles needed for practical cloud seeding (Fukuta, 1972).

It has been shown in experimental and theoretical studies that organic particles in a size range of 0.1 μm radius or slightly less are most suitable for cloud seeding purposes. An airborne generator of MA smoke using the chemical in the powder form fluidized with Cab-O-Sil was developed (Fukuta, 1967) and was tested in summertime cumuli (Fukuta, 1972). As reported, the seeding demonstrated a clear effect of ice phase precipitation element formation on the radar screen. The smoke generator was, however, too bulky and awkward for operational applications. For this reason, an extensive effort has been put forth in our laboratory to design practical smoke generators for the above organic nucleants.

In this paper, we shall discuss the newly developed airborne organic smoke generator utilizing the jet mixing method of smoke production and its field test using DN in summertime cumuli over the Rapid City area of South Dakota in August 1974. The field program was in cooperation with the Division of Weather Modification, South Dakota Department of Natural Resource Development.

II. NEW JET MIXING AIRBORNE GENERATOR OF ORGANIC SMOKE

The principle used in the airborne generator is that of the jet mixing method of vapor condensation for smoke particle production. In the method, a water suspension of the nucleant is sprayed directly into the hot exhaust gas of an aircraft engine. The suspension droplets rapidly vaporize in the hot environment and the vapor mixture is quickly quenched by mixing with the cold air moving past the aircraft. The rapid quenching results in organic particles of about 0.1 μm in radius as confirmed in the laboratory. The exhaust gas of the aircraft engine provides a free heat source for the vaporization process. The exhaust gas has proven to be harmless to the nucleating activity of the smoke particles produced.

Fig. 1 shows schematically the structure of the new airborne generator. Fig. 2 gives the actual view of the generator installed on the side of one of the engines of the Piper Aztec aircraft used in the field program. The generator consists of a steel tube 75 cm long, with an outside diameter of 12.5 cm, and a wall thickness of 1.6 mm. The engine exhaust gas is delivered to the generator by means of an extension elbow 7.5 cm in diameter which passes through a steel flange end plate. The exit plane of the generator is open allowing the exhaust gas, steam, and organic vapor to pass through. The extension elbow and the main body of the generator are covered with asbestos cloth to minimize the cooling due to the cold air passing by these components.

The nozzle used to spray the nucleant and water mixture is a hollow cone stainless steel Whirljet Spray Nozzle, model 1/8 A0.5. It is located on the centerline of the generator tube at the exit plane of the exhaust pipe elbow as shown in Fig. 1. The suspension is pumped from a 19 ℓ tank located in the cabin of the aircraft to the nozzle using a variable delivery pressure pump. The 12 volt FMI Lab Pump, model RP-BCA, is capable of delivering from 0 to 750 ml of mixture per minute at a maximum pressure of 5.7 bars (70 psig). A diagram of the delivery system is shown in Fig. 3.

It was determined during the start of the testing program that the delivery line between the pump and the nozzle needed to be purged immediately after a seeding operation. This was necessary because any residual organic material in the nozzle would decompose under the extreme heat of the engine exhaust gas and ultimately plug the fine orifice of the nozzle. The purging was accomplished using a small cylinder of compressed air connected to the delivery line through the three-way valve.

The delivery line is 6.25 mm wire-wound tygon tubing, 2.4 m long. In order to prevent the freezing of the suspension in the tubing at high altitudes, the steel reinforcement wire of the tubing was connected to the 12 volt power source of the aircraft. This provides 20 watts of heating along the delivery line which proved to be adequate for the purpose. The delivery line was also wrapped with insulation. The centerline temperatures of the generator at the inlet and exit planes are measured using chromel-alumel thermocouples. During the seeding operations the temperature of the exhaust gas just prior to the spray nozzle was measured to be 650°C. Before spraying, the temperature of the generator exit plane was 500°C. This dropped to 480°C when the nucleant and water mixture was sprayed at a rate of 5 gm per second. The gauge shown in Fig. 3 is used to monitor the delivery line pressure to the nozzle.

III SEEDING PROCEDURE

The seeding procedure conducted during this program is as follows. Except for the first test case, in which the cloud was seeded below the base, the nucleant was released during direct penetrations through the clouds usually at the -5°C level. This normally involved one penetration. A 5% by weight suspension of DN in water, delivered at a rate of 5 gm sec^{-1} to the nozzle, was used for all tests. The seeding altitude was usually between 16,000 (4.9 km) and 17,000 (5.2 km) ft. The typical sizes of the clouds seeded were 2 to 5 miles in diameter, with cloud heights being less than their widths. The aircraft speed during the seeding was maintained to be 110 knots (57 m sec^{-1}). The type of clouds seeded was usually isolated cumulus. Aircraft windshield glaciation during the cloud penetration at -5°C or colder was checked and considered as the measure of the liquid water content (LWC) of the cloud - and thus its potential seedability. The LWC has been qualitatively classified as low, moderate, or high by personnel aboard the aircraft. The method used to evaluate the seeding effects involved visual observations during which photographs were taken to detect vertical development, anvil formation, glaciation, and virga formation with respect to time and altitude in comparison with similar control clouds selected. Once a cloud was seeded, the usual procedure was to fly to a higher altitude in a westerly direction to an observation area approximately 10 miles from the test case. This allowed the cloud to be viewed and photographed under optimum conditions relative to the position of the sun. The airplane would then proceed to execute controlled 360° turns, so that at, say, 5 minutes intervals, the airplane would be in the same position to observe the test case. The details of the log of all seeding operations can be obtained upon request.

IV. RESULTS OF SELECTED CASES

During this testing program the cloud conditions in the Rapid City area were generally unfavorable. Of the 19 days in which the generator was operational, on only 4 did clouds occur which contained sufficient supercooled liquid water to satisfy a reasonable seedability requirement. The remainder of this section will discuss four test cases occuring on 2 of these 4 days.

Two clouds with high LWC were seeded on August 22, 1974. The atmosphere on this day was relatively unstable, being indicated by the existence of large storm activities in the area and the presence of reasonably tall clouds. Cloud 1 is shown in Fig. 4. The first photograph was taken through the aircraft windshield as it approached the cloud 2 minutes before seeding. The cloud was observed to be in a building stage. The cloud was seeded at -5°C (16,000 ft) for 20 seconds, and 11 minutes later at -8°C (17,000 ft.) for 30 seconds with a total of 10 gm of DN. Twenty minutes after the first seeding, strong vertical development was already evident. The cloud completely glaciated into a cirrus type, as seen 65 minutes after the initial seeding. Virga from the cloud base was observed (not shown in these photographs) 25 minutes after the first penetration. Similar control clouds in the immediate vicinity of this test case, as well as for all the following cases to be discussed, did not shown signs of vertical development, glaciation, or virga formation, during the same period of observation.

In general for an unstable atmosphere, when a cloud was seeded at the -5°C level by penetration, it usually took about 20 to 25 minutes to develop virga of good intensity. The vertical development was observed to start at about 5 to 10 minutes after seeding.

The second cloud seeded on August 22, 1974 is shown in Fig. 5. The cloud was seeded at -14°C (20,000 ft) for 75 seconds with a total of 15 gm of DN. The cloud was thus seeded in a highly supercooled zone. A very rapid anvil formation happened without developing strong virga, indicating a possible overseeding effect. The cloud base apparently came up without increasing the total height of the cloud.

The first test case of August 24, 1974 is shown in Fig. 6. The atmosphere on this day was classified as unstable. The LWC of this cloud was moderate. The cloud was seeded at -5°C (16,500 ft) for 181 seconds with 36 gm of DN. Vertical development, glaciation and virga formation occurred as seen in the figure.

Cloud 2 of August 24, 1974 is shown in Figs. 7 and 8. The seeding effects on this test case were most dramatic. Fig. 7 shows airborne observations of the cloud while Fig. 8 shows ground base observations from the radar facility at the Rapid City Airport. The LWC of this cloud was high. The cloud was seeded at -5°C (17,000 ft) with 32 gm of DN. Strong vertical development quickly occurred. The cloud top was initially estimated to be at an altitude of about 20,000 feet. 13 minutes after seeding, the pilot estimated that the top had risen to 25,000 ft to 30,000 ft. The cloud development led to a glaciated anvil formation. Virga was observed from both the top and bottom portion of the cloud just 10 minutes after seeding. The virga increased in intensity from the cloud base as time progressed. Eventually the cloud became completely glaciated and formed into a cirrus type stretching tens of miles.

At the time of seeding, the cloud location was at a VOR-DME reading of 235° - 20 nautical miles from the Rapid City VORTAC station. The cloud location 45 minutes after seeding was at a VOR-DME reading of 230° - 20 nautical miles. The cloud was therefore moving laterally in relation to the radar facility where the photographs of Fig. 8 were taken. These photographs thus give an accurate perspective of the cloud development.

V. SUMMARY AND CONCLUSIONS

The results of this short program demonstrates the effectiveness of 1,5-dihdroxynaphthalene under actual field conditions. The evidence is strong that when sufficient supercooled liquid water is present in the seeded cloud, the cloud reacts in an expected manner although the evaluation methods we employed were of semiquantitative nature. It has also been established that the extremely simple jet mixing type generator is capable of delivering this organic material in a form suitable for cloud seeding purposes.

The importance of cloud seeding agents in weather modification can hardly be overestimated. It should be recognized that there is a definite need for cloud seeding materials which are not only effective but also economical, biodegradable and free of other secondary problems such as the downwind effect. DN is one organic nucleant which satisfies these requirements. Before the developed technology on DN smoke production is handed over to the programs of experimental as well as operational seeding, a truly quantitative field test must be carried out. The need of such a test is obviously acute, for the future of weather modification largely depends on the new generator technology of seeding agents.

VI. ACKNOWLEDGMENTS

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VII. REFERENCES

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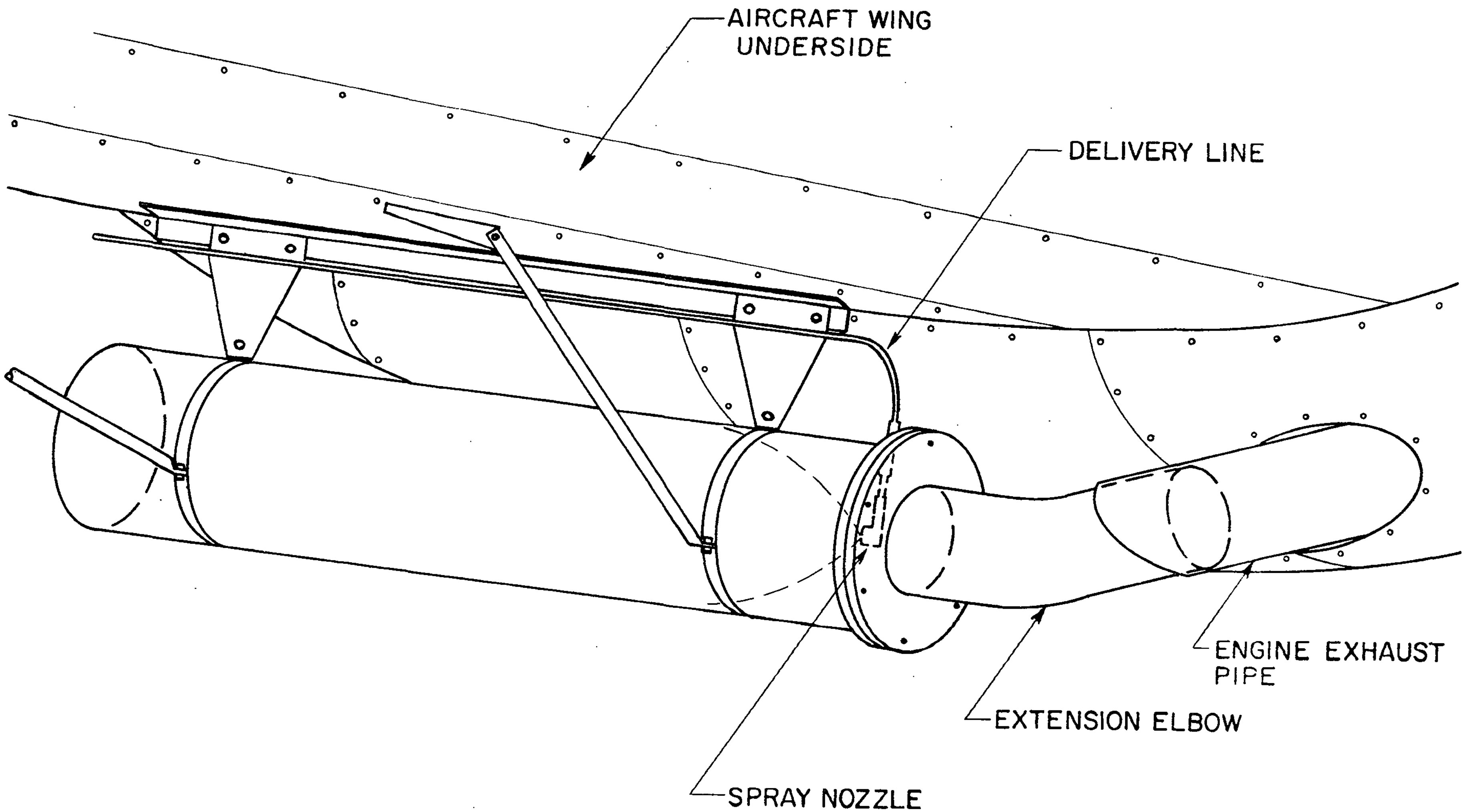


Drawing of generator mounted to aircraft wing

Figure 1

Jet mixing type generator mounted under the wing of the Piper Aztec airplane.

Figure 2

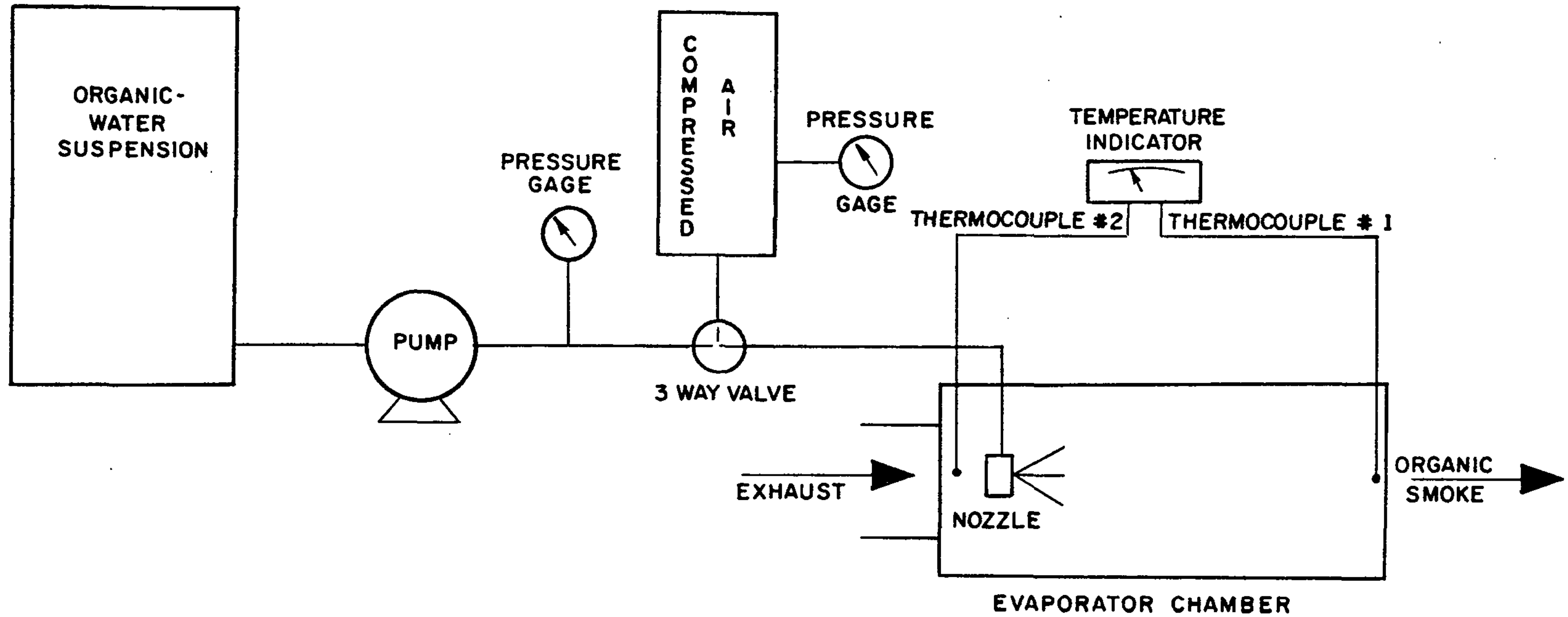
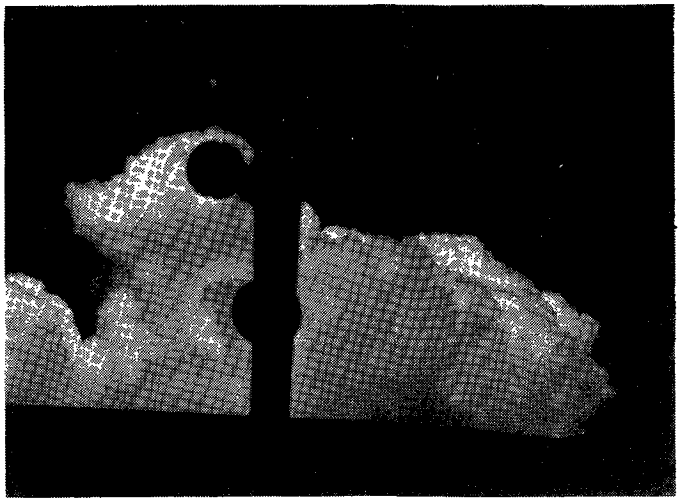


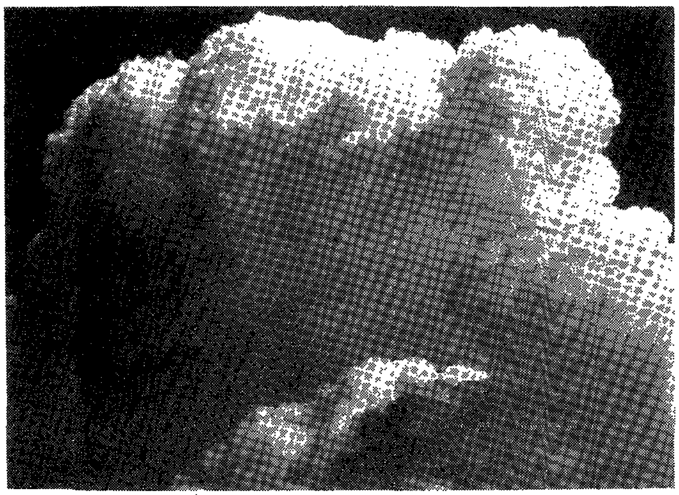
Diagram of the organic suspension delivery system

Figure 3



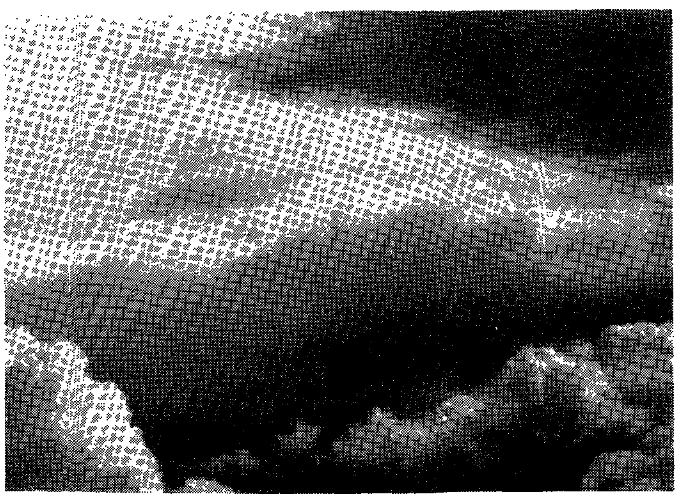
2 minutes before seeding

Aircraft altitude: 16,000 ft



20 minutes after seeding

Aircraft altitude: 20,000 ft

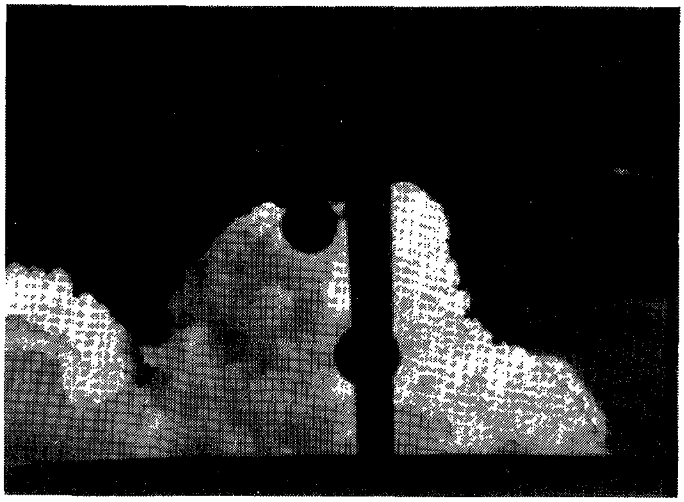


65 minutes after seeding

Aircraft altitude: 20,000 ft

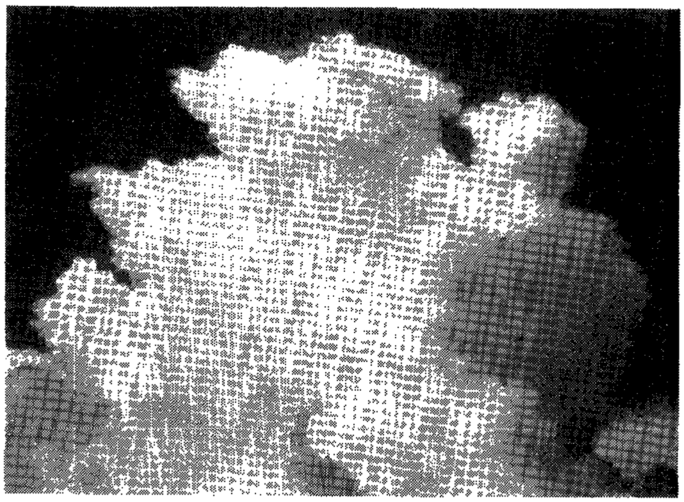
Cloud 1 seeded at -5°C (16,000 ft) for 20 sec and at -8°C (17,000 ft) for 30 sec, total of 10 gm of DN. August 22, 1974, Rapid City, S. Dakota.

Figure 4



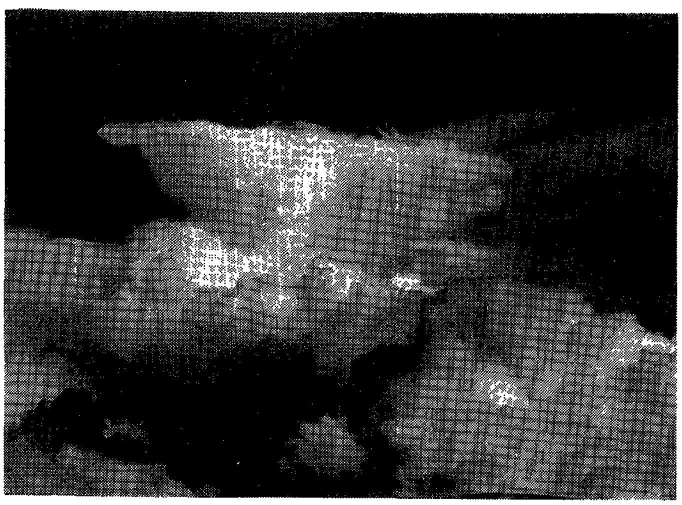
2 minutes before seeding

Aircraft altitude: 20,000 ft



13 minutes after seeding

Aircraft altitude: 20,000 ft

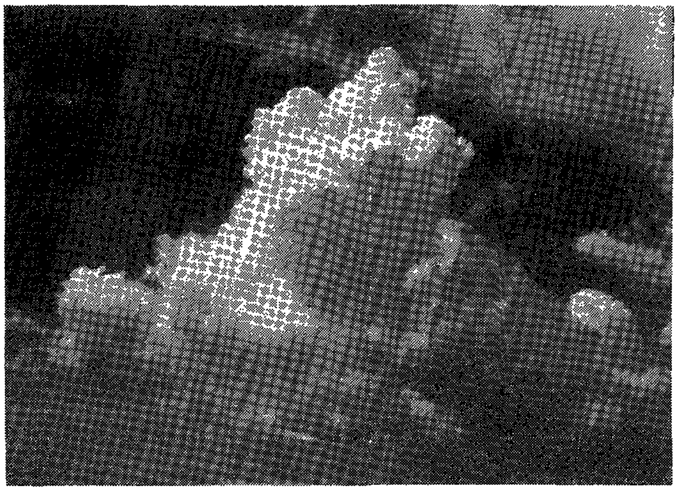


15 minutes after seeding

Aircraft altitude: 20,000 ft

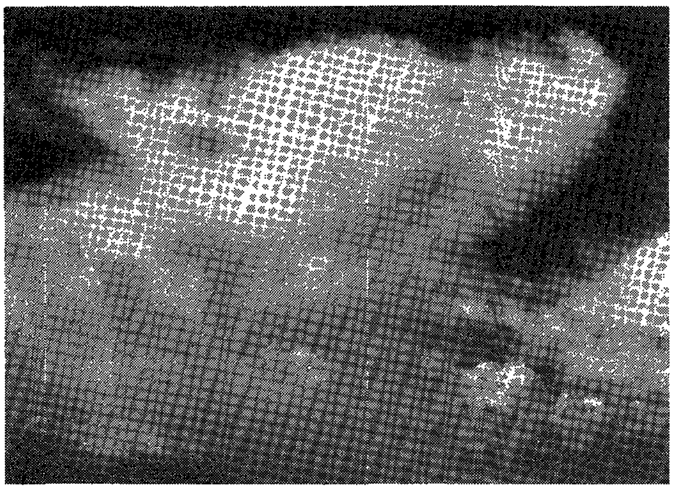
Cloud 2 seeded at -14°C (20,000 ft) for 75 sec, total of 15 gm of DN.
August 22, 1974, Rapid City, S. Dakota.

Figure 5



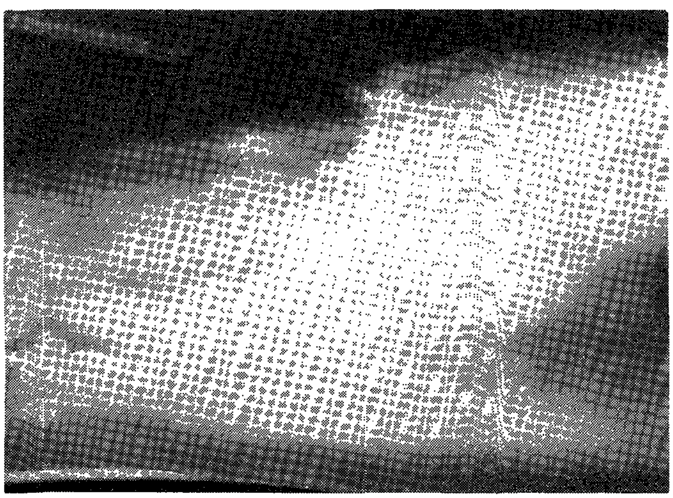
5 minutes before seeding

Aircraft altitude: 16,500 ft



10 minutes after seeding

Aircraft altitude: 18,000 ft

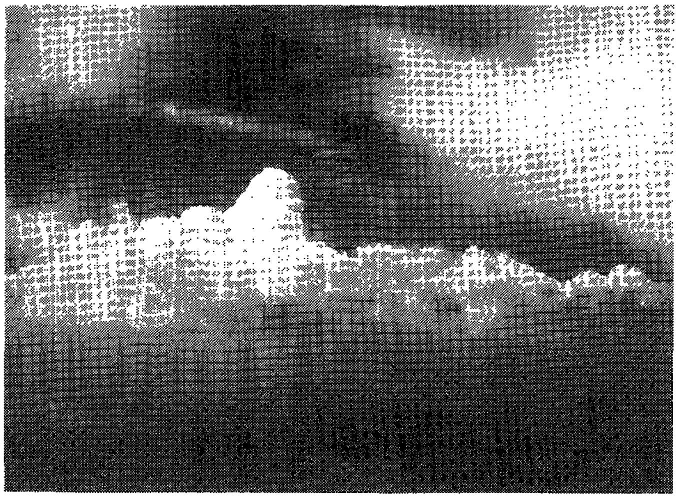


26 minutes after seeding

Aircraft altitude: 18,000 ft

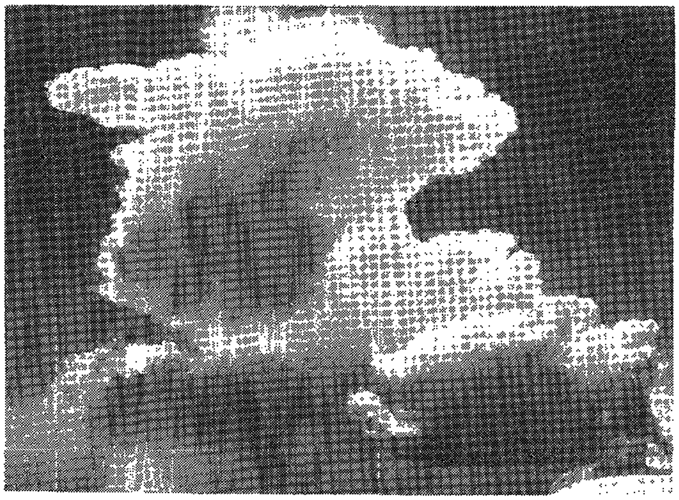
Cloud 1 seeded at -5°C (16,500 ft) for 181 sec, total of 36 gm of DN. August 24, 1974, Rapid City, S. Dakota.

Figure 6



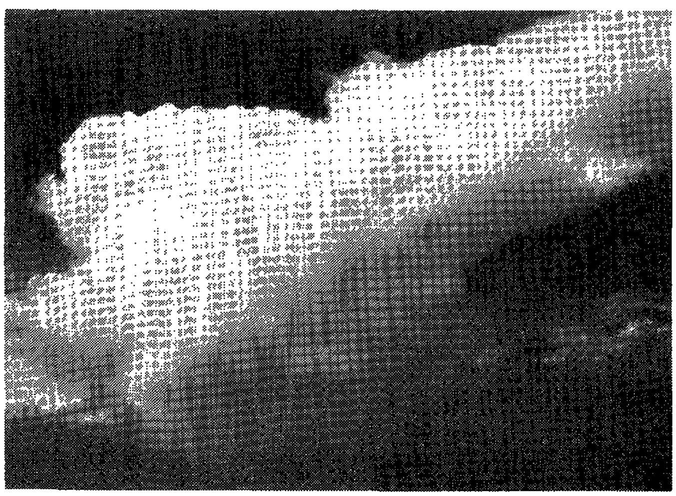
3 minutes before seeding

Aircraft altitude: 17,000 ft



12 minutes after seeding

Aircraft altitude: 18,000 ft



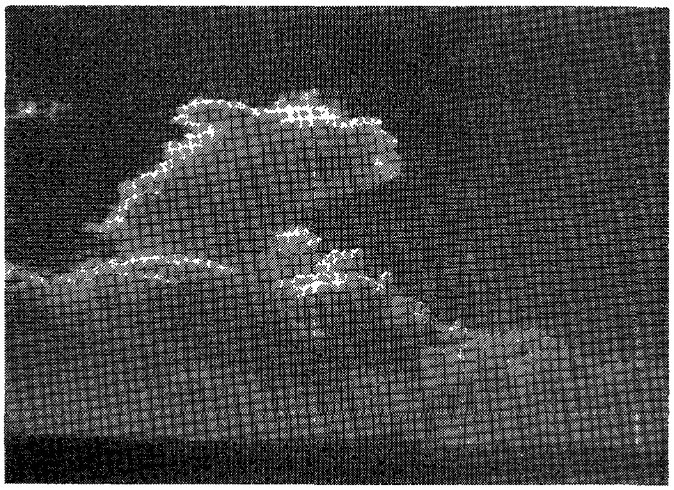
19 minutes after seeding

Aircraft altitude: 18,000 ft

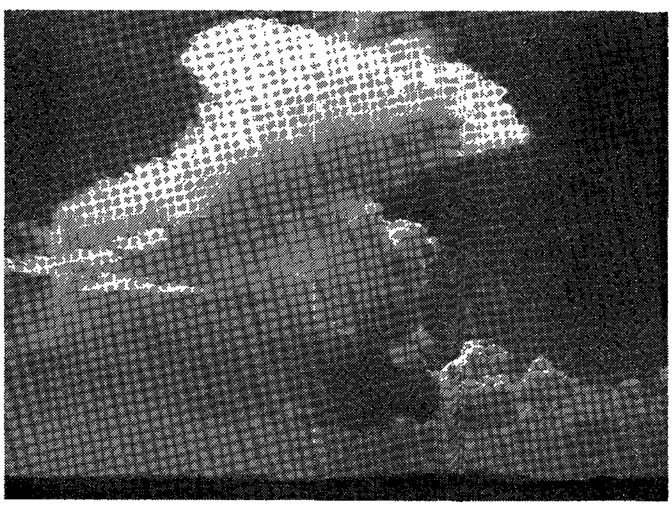
Cloud 2 seeded at -5°C (17,000 ft) for 161 sec, total of 32 gm of DN.
August 24, 1974, Rapid City, S. Dakota.

Figure 7

6 minutes after seeding



14 minutes after seeding



24 minutes after seeding

Cloud 2 seeded at $-5^{\circ}C$ (17,000 ft) for 61 sec, total of 32 gm of DN. Photos taken from the ground, approximately 22 nautical miles from the cloud. August 24, 1974, Rapid City, S. Dakota.

Figure 8

APPENDIX A

MAJOR FEATURES OF ORGANIC ICE NUCLEI GENERATORS

(1) ECONOMY

	Price (Industrial, average, $/lb)	
Metaldehyde	0.9 - 1	
1,5-Dihydroxynaphthalene	3 - 4	
Phloroglucinol	8 - 10	
AgI	130.0	pyrotechnics
	55	raw material

The price of Ag went up by a factor of 3 last year.

(2) ECOLOGY

	Bacteria	Algae	Fish (incl. baby)
Organics	Grow	Grow	Grow
AgI (at its solubility= 3×10^{-9})	Some effect	No appreciable change	Killed

(3) DOWNWIND EFFECT

Due to evaporation of small particles, the downwind effect of organic ice nuclei is null or minimal.

(4) AIRCRAFT SAFETY

Organic (suspension in water); not flammable

AgI in Acetone
Pyrotechnic device ; combustible

(5) LONG TERM AVAILABILITY

Organics; good

AgI ; poor

(6) HIGH ACTIVITY AT WARM TEMPERATURES

Supersonic nozzle method