The Development and Testing of an Airborne Droppable Pyrotechnic Flare System for Seeding Alberta Hailstorms

PETER W. SUMMERS

Research Council of Alberta, Edmonton, Canada

GRAEME K. MATHER[1] AND DENNIS S. TREDDENICK[1]

National Aeronautical Establishment, Ottawa, Canada

(Manuscript received 9 February 1971, in revised form 4 February 1972)

ABSTRACT

Many of the severe and persistent hailstorms in Alberta propagate by means of new cloud development on the southern or western flank. A concept is proposed whereby these cumulus towers are seeded with freezing nuclei early in their development. In order to accomplish this a droppable pyrotechnic flare system was developed and tested.

A T-33 jet aircraft was used as the seeding platform. It was equipped with a Ku-band weather radar, a flare rack and firing control panel, a 14 channel recorder and a 3-cm transponder. Seven inch pyrotechnic flares were manufactured to the following specifications: delay burn 50 sec, silver iodide burn time 30 sec, and flare output 24 gm of silver iodide producing a total of 2.4×10^{14} freezing nuclei active at -10C. A unique feature was the incorporation of 10-cm radar chaff which was released at flare burn-out and used as a position marker. Flare performance was evaluated using radar, visual and photographic tracking. Total fall distance as a function of release height was determined. For typical drop altitudes used to seed storms the flares fell 9500 ft with the silver iodide being released during the last 2700 ft.

In the summers of 1970 and 1971 the seeding system was used on sixteen occasions in experiments which emphasized physical understanding rather than statistical inference. On two occasions turbulence measurements were made in cumulus towers with a second T-33 aircraft. The calculated dissipation rates indicate that there is sufficient diffusion to produce silver iodide nuclei concentrations in excess of 100 liter^{-1} active at -10C through cloud volumes of several cubic kilometers within a few minutes after seeding.

The operational logistics of this seeding system are quite straightforward and the system appears to be a practical one for applying the direct injection seeding technique to multicell hailstorms. By means of radio communication between the project control room and the seeding aircraft, it was always possible to unambiguously identify and seed the selected target storm. The radar chaff was of limited usefulness as a marker of seeding location.

1. Introduction

Hail occurs in central Alberta on an average of 66 days every summer, with 13 of these classified, on the basis of areal extent, as major hail days (Summers and Paul, 1967). Analysis of 33 years of hail insurance data indicates that 80% of the total hail damage each summer occurs on the twelve worst days (Summers and Wojtiw, 1971). It is thus evident that an effective operational system of hail suppression in Alberta must be able to cope with the dozen or so worst days when these persistent storms produce long damaging hailswaths.

Although a wide variety of methods have been suggested for suppressing hail, the only serious operational or experimental attempts during the last two decades have involved seeding with freezing nuclei, usually silver iodide. However, the question of when, where and with how many such freezing nuclei a hailstorm should be seeded to produce the optimum suppression effect is still far from being resolved. The basic concept generally accepted as being realistic with current seeding technology is to increase the number of hail embryos competing for the given water supply, thus producing more but smaller hailstones. An empirical relationship between hail damage to grain crops in Alberta and the size and amount of hailfall shows that the same mass of hail distributed among more but smaller stones will decrease the probability of severe damage (Summers and Wojtiw).

Several different techniques have been used to deliver seeding material into hailstorms. Early efforts relied on blanket seeding the whole airmass in which the storms were expected to develop using a large number of ground generators. In the mid 1950's aircraft were first used for cloud-base seeding of the air entering storm systems, and were put to general use in the 1960's. More recently, methods have been developed for injecting the seeding

---

[1] Present affiliation: Sierra Research Corporation, Boulder, Colo.

material directly into a small volume of single storm cells using projectiles.

Schleusener (1968) reviewed the published results from many hail suppression projects and concluded that the available evidence (up to 1967) supports the hypothesis that major hailfalls can be reduced by heavy seeding rates of greater than 2000 gm hr^{-1} of AgI per storm.

The only projects to date which consistently show apparent substantial reductions in hail damage over large areas are those conducted in the USSR since the mid 1960's. In 1969 the total area under protection in seven separate projects amounted to over six million acres (Battan, 1969). All of these projects used anti-aircraft guns (Sulakvelidze, 1968) or ground-based rockets (Kartsivadze, 1968) to deliver the seeding material at a critical time in the storm's development into a target zone precisely defined by its radar structure and temperature range. Some success has also been reported from recent experiments using cloud-base seeding by aircraft on moderate intensity storms in the Dakotas (Schleusener. *et al.*, 1970) and in Kenya (Henderson, 1970). In southwestern France, a combination of methods using aircraft and ground-based rockets for cloud-base seeding and also droppable pyrotechnics has given a statistically significant reduction in several hailfall parameters since 1966 (Picca, 1971).

It thus appears that a direct injection technique that can deliver large amounts of freezing nuclei into a storm at a critical place and time in its development offers the most promise for suppressing hail from severe travelling storms. Unfortunately, use of the Russian technique in the major hail belts of Alberta is precluded because of the high density of commercial and light uncontrolled air traffic. Also the very large area ($\sim$75,000 mi^2) in need of protection would almost certainly make the system uneconomical. An alternative system of direct injection is therefore required.

2. Characteristics of Alberta storms

Analysis of time-lapse cloud movies and radar records of Alberta storms shows that most of the persistent type storms propagate strongly to the right of the mid-tropospheric winds by means of new development occurring on the southern flank. A study of 89 persistent storms during the period 1956–68 showed that the hailswath orientation averaged 25° to the right (looking downswath) of the wind direction at 500 mb. A few of these storms exhibit near steady-state features and appear to be of the supercell type with a large weak-echo region, but with no new cloud towers observed on the flanks (Marwitz and Berry, 1971). However, more frequently the severe storms in Alberta appear to be of the multicell type with distinct new surges of activity appearing, at intervals of 5–15 min, as one or more large cumulus towers rising rapidly on the southern or western flank and then merging with the parent storm. These clouds are akin to the "feeder clouds" observed in South Dakota (Dennis *et al.*, 1970), but in Alberta they seldom start as distinct separate entities, and instead begin either immediately adjacent to, or are sometimes observed bulging out from, the side of the parent storm. The first radar echo usually appears aloft at about 20,000 ft. Shortly afterward the cloud towers lose their visual identity as they merge with the parent storm, but the radar echo rapidly grows in size and can be followed as a distinct entity for 15–45 min as it moves in the direction of the mid-level tropospheric winds through the storm complex (Chisholm, 1966; Renick, 1971). Thus, while the storm is persistent in the sense that it moves as a clearly identifiable mesoscale feature and lays an almost continuous hailswath on the ground, wide variations in the hail intensity are observed.

3. The experimental concept

The new cloud developments are the generation regions for the precipitation which will be reaching the ground 15–30 min later (Renick, 1971). This suggests that the hail suppression concept outlined earlier could be applied by heavily seeding these cloud developments early in their life in an attempt to substantially increase the number of ice particles entering the storm system. Measurements indicate greater turbulent dissipation rates and initially smaller updraft velocities in these cumulus towers than in the main updraft core of the storm (Marwitz and Berry, 1971). Thus, seeding material introduced into the new growth regions will be diffused more rapidly. Also, the longer residence time of the artificial ice nuclei will allow more time for the nucleation and subsequent growth of the ice particles to hail embryo size.

The experiments are being conducted under the designation "Project Hailstop" as part of the Alberta Hail Studies Program.[2] The experiments are emphasizing physical rather than statistical evaluation. No fixed target area is defined, but all seeding takes place within useful radar range of Penhold (see Fig. 1). Suitable well-developed hailstorms are selected and several successive new cumulus towers are seeded. The storm system is closely monitored prior to, during and after seeding, utilizing the observational facilities built up over the last fifteen years. All observed events can then be related to the precisely known time and place of the seeding event (Summers and Renick, 1971).

At this stage in the experiments, emphasis is being placed on detecting reproducible changes in some or all of the monitored parameters which may be attributable to the effects of seeding. If necessary, randomized statistical experiments can be designed around the most sensitive parameters at a later date.

---

[2] A cooperative investigation into all aspects of hailstorms being carried out jointly by the Research Council of Alberta, the National Research Council of Canada, the Canadian Atmospheric Environment Service, and the Stormy Weather Group of McGill University, Montreal.

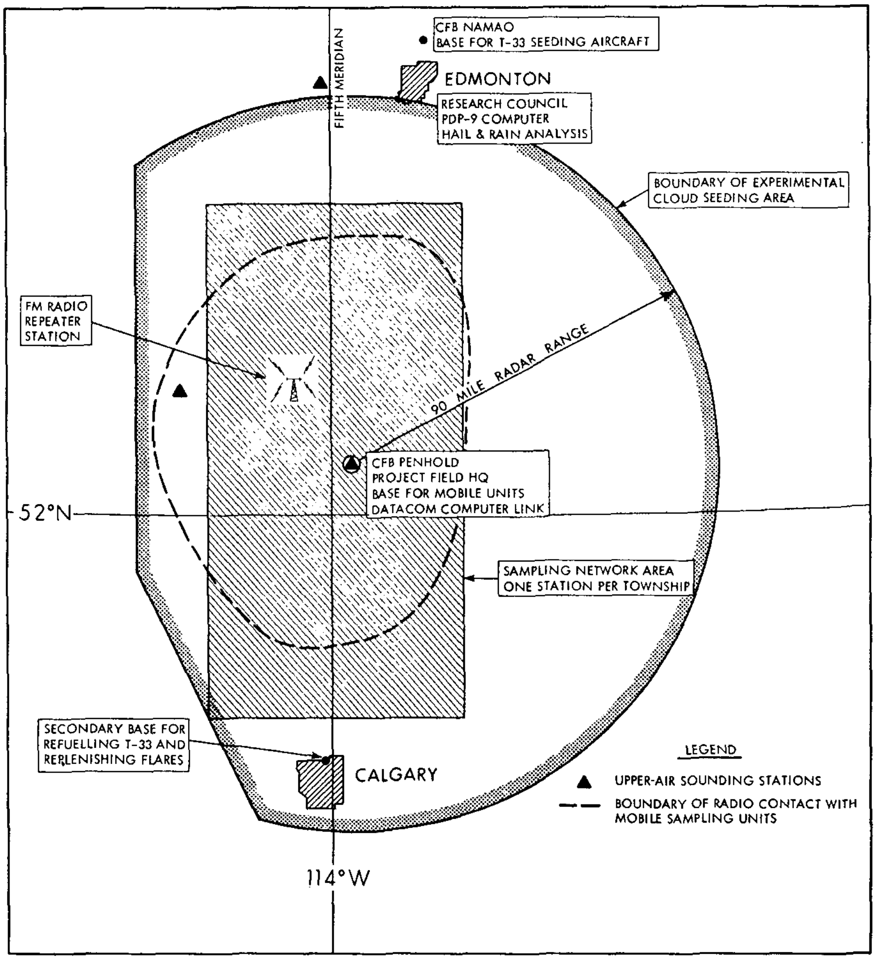

Fig. 1. Map showing the Alberta Hail Studies project area and deployment of facilities for Project Hailstop.

4. The seeding system

a. Design criteria

A study of 157 days with major hailstorms in Alberta showed that on these days the average height of the −5C level in the environment was 13,500 ft MSL.[3] Inside the cumulus towers the −5C level would thus be between 15,000 and 16,000 ft. Since it was desired to put the silver iodide into the temperature zone −5 to −12C, the region where most hail embryos are thought to originate, the mean height of the target zone was defined as 15,000–18,000 ft.

Previous aircraft observations indicated that these developing cumulus towers could be recognized as they grew through the 15,000-ft level. It thus appeared that droppable pyrotechnic flares similar to those used in the Florida cumulus experiment (Simpson *et al.*, 1970) could be adapted to seed these towers from an overflying aircraft. The optimum flight altitude was chosen to be 20,000–25,000 ft. This would allow the aircraft to make seeding runs without having to penetrate the cumulus tops too often, yet keep the flare fall distance short and minimize targetting errors. Allowing for updrafts of 5–15 m sec^{-1} inside the cumulus towers required that the flares have a free fall distance of approximately 10,000 ft.

It was desired to increase the number of freezing nuclei by a factor of >100 above natural background and produce a concentration $>10^2$ liter^{-1} active at −10C through a substantial volume of the cumulus tower several minutes after seeding. The available data for the rate of diffusion in cumulus congestus clouds indicated that the required concentration could be produced by dropping flares at 1000-ft horizontal intervals, provided that each flare generated $>5\times10^{13}$ nuclei active at −10C.

b. The flares

Prototype test flares were manufactured by Olin Corporation according to the following specifications:

First fire and delay burn	50 sec
Silver iodide mix burn	30 sec
Total nuclei output active at −10C	$>5\times10^{13}$

---

[3] All heights are above mean sea level.

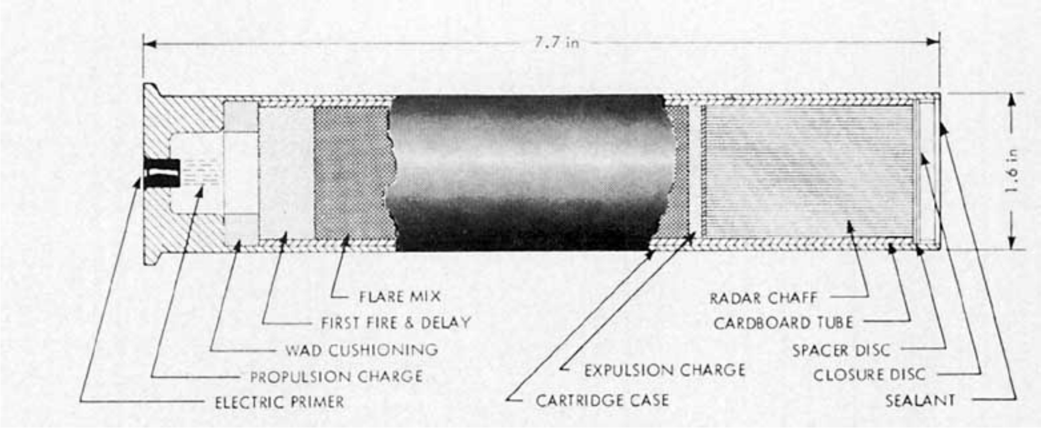

FIG. 2. Cut-away diagram of the pyrotechnic seeding flare containing radar chaff.

Ten of the test flares contained, in addition to the AgI mixture, a bundle of 10-cm radar chaff. This was released at the end of the AgI burn so that radar detection could be used for confirming targetting accuracy.

The prototype flares were tested using visual and radar tracking and met the design burn time specifications. A slight improvement in the first fire was requested to give more reliable ignition in the production run. A schematic cut-away of the flare is shown in Fig. 2.

c. *The seeding aircraft*

The National Aeronautical Establishment (NAE) modified and instrumented a T-33 single engine jet aircraft (Fig. 3) to provide the flare delivery system. The T-33 is a rugged aircraft, capable of achieving the altitudes required for on-top seeding, and it has sufficient speed and maneuverability to meet the rapid deployment requirements of the experimental design.

A 52-round pyrotechnic flare rack was installed in a modified luggage pod (Fig. 4). The magazines can be easily removed and reloaded in less than 2 min. Firing of the AgI flares is controlled from a panel located in the rear seat position. The flare rack is split into two banks—one for the chaff flares and the other for no-chaff flares. Each bank has a separate counter and reset switch. The flares are fired singly from either the front or rear seat positions by a push button on the aircraft control stick. Any sequence of chaff and no-chaff flares can thus be released on a seeding run.

A 14-channel galvanometer film recorder is used to record aircraft altitude, airspeed, ambient temperature, normal acceleration, a time code, flare firing and other manual events. All crew comments and air-to-ground transmissions are recorded on a voice recorder. A digital clock with a read-out in seconds was included in the firing control panel. A time reference in binary code is placed on the film recorder every two minutes.

A Ku-band (1.9 cm wavelength) weather radar was installed in the nose of the aircraft and protected by a custom-built radome. The display and controls were mounted on the instrument panel in the rear seat. Photographs of cloud developments before and after seeding are taken with a hand-held 35-mm camera from the rear seat.

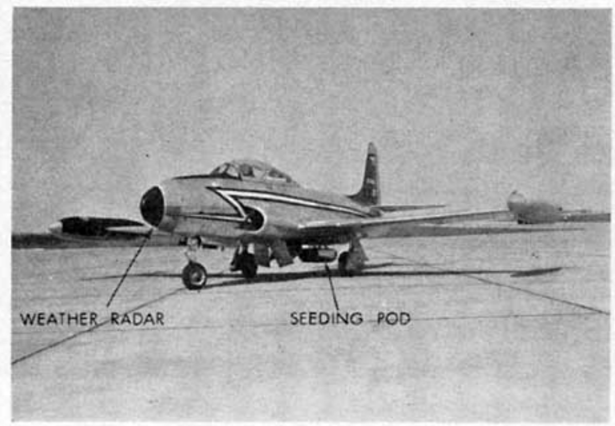

FIG. 3. The National Aeronautical Establishment T-33 seeding aircraft.

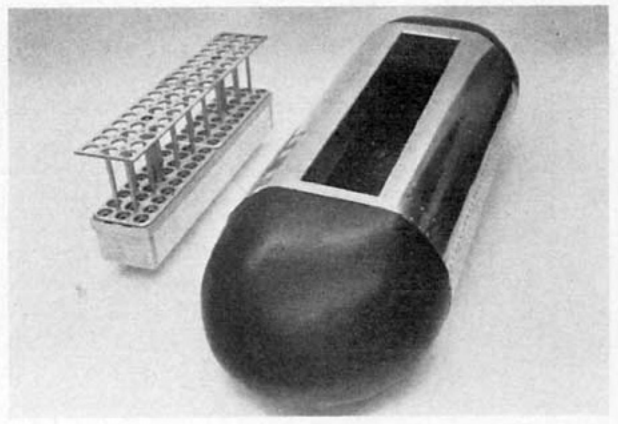

FIG. 4. The 1970 version of the seeding pod and flare rack.

TABLE 1. Summary of flare characteristics obtained by time-lapse photography.

Release altitude (ft)	Total fall distance to burn-out (ft)		Difference between chaff and no-chaff (ft)	Mean terminal velocity (ft sec^{-1})		Depth of seeding plume produced during final 30 sec (ft)
	Chaff	No-chaff		First 10 sec photo tracking*	Final 10 sec	
18,000	8000	7975	25	198	71	2700
20,000	8800	8650	150	202	78	2600
22,000	9650	9400	250	193	71	2600
24,000	10275	9725	550	227	83	2900

* Approximately 25–35 sec after release.

d. Flare performance

Several preliminary tests of the production run flares were made, following the flare down by the aircraft flying a tight spiral around the flare trajectory.

To obtain more detail on the variation of flare fall-speed with height and also on the relation between total fall distance and release height, a test was made on a clear night with light winds. Four runs were made at flight altitudes of 18,000, 20,000, 22,000 and 24,000 ft. Two chaff flares were dropped close together at each end of the run for radar ranging. Four no-chaff flares were dropped at approximately 0.5-mi intervals between the chaff markers. Time-lapse photography was used to record the drops from a distance of 10 mi. A 0.5-sec exposure was made every 1.85 sec. The elevation angle of each flare on every frame of the film record was determined to an accuracy of 0.1° on a computer drawn projection grid which incorporated corrections for camera tilt. Height vs time graphs for each flare trajectory were then computed. Each group of chaff and no-chaff flares for each of the four release altitudes was averaged. Some of the flare performance characteristics obtained by this method are given in Table 1. Heights are rounded to the nearest 25 ft. The depth of the seeded plume was calculated assuming an AgI burn time of 30 sec, which was confirmed by the earlier visual tracking.

Table 1 indicates that the terminal velocity of the flares just before burn-out is only about one-third of that shortly after release. This is illustrated in Fig. 5 which shows a series of multiple 5-sec exposures taken at 5-sec intervals during one of the test runs.

For accurate targetting an important flare characteristic is the reproducibility of the total fall distance. Thus, for each flare the departure of its burn-out altitude from the mean value of its batch was calculated. The departures ranged from +950 ft to −600 ft with an overall standard deviation for 30 flares of 346 ft. Thus, 95% of the flares dropped in clear air will burn-out within ±700 ft of the desired altitude, which is within the experimental limits.

TABLE 2. Nucleation efficiency of the flares.

Temp (°C)	Effective nuclei per gram AgI	Effective nuclei from whole flare
− 5	8×10^{10}	1.9×10^{12}
−10	1×10^{13}	2.4×10^{14}
−15	7×10^{14}	1.7×10^{16}
−20	4×10^{15}	9.6×10^{16}

The chaff flares weigh 226 gm and the no-chaff flares weigh 197 gm. This difference in weight accounts for the greater fall distance of the chaff flares shown in Table 1. The effect is more pronounced the higher the drop altitude, but even at a maximum of 500 ft, the difference is not significant when using these flares as a height marker.

e. Flare reliability

During the various tests a total of 66 flares were released. Ignition was confirmed on 61 of these, giving an ignition reliability of 92%. This is certainly adequate when dropping 10–20 flares at close intervals on a seeding run. The damage hazard at the ground from an unignited flare is no greater than from a large hailstone.

f. The silver iodide mixture

Each flare contains 50 gm of Olin formulation WM 105 which produces 24 gm of AgI when burned.

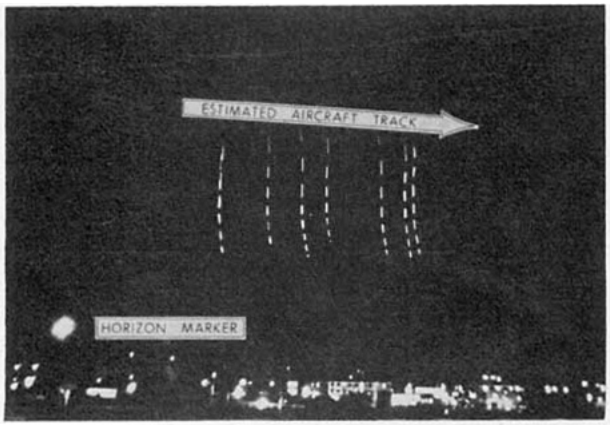

FIG. 5. Series of multiple 5-sec exposures with a 5-sec interval of a nighttime release of eight flares (note that the first two are superimposed).

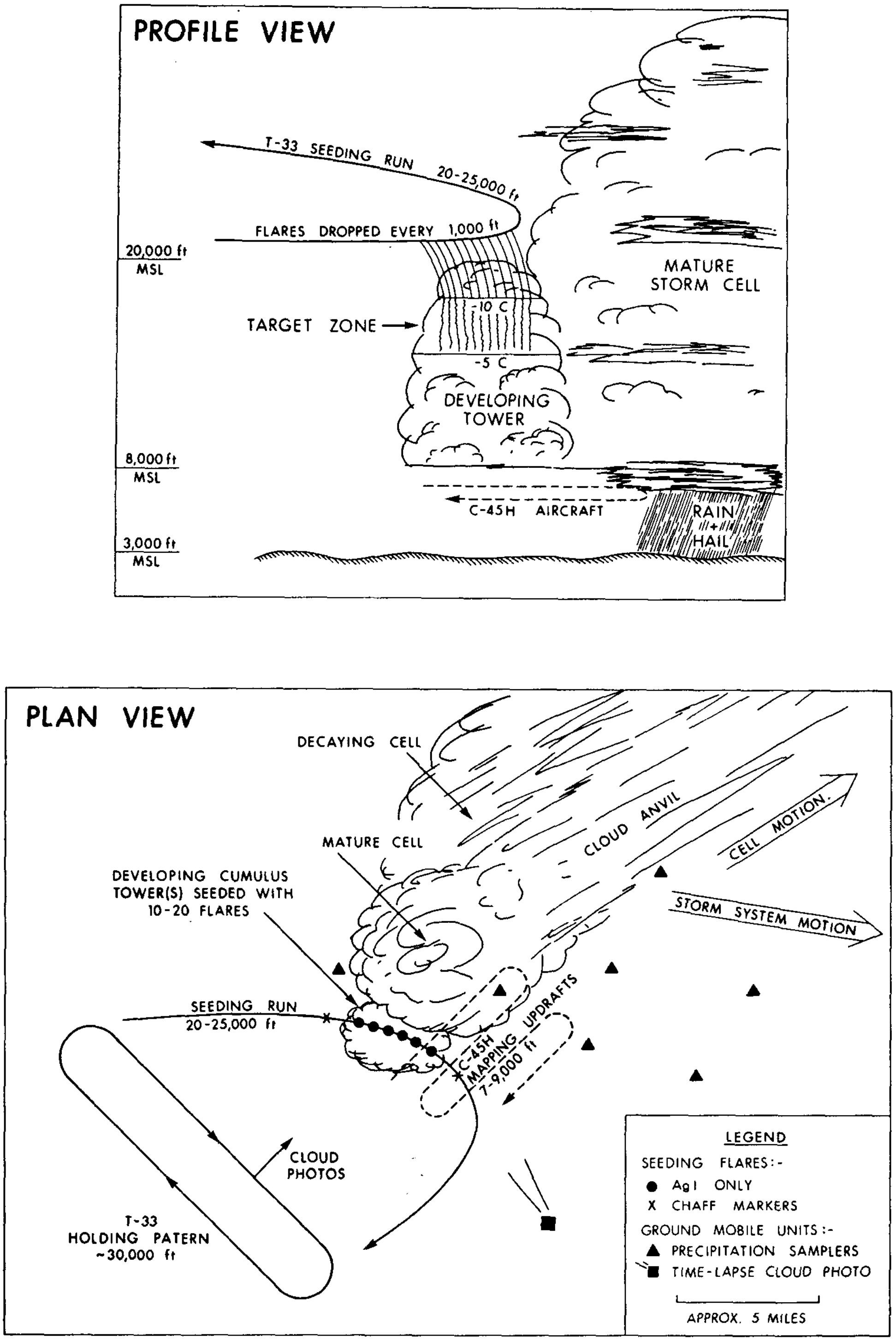

Fig. 6. Schematic illustration of the operational logistics for the seeding experiments.

The formulation has the following per cent composition by weight: silver iodate (53%), strontium nitrate and potassium iodate oxidizer (19%), magnesium and aluminum fuel (18%) and binder (10%). Tests performed in the Colorado State University cold chamber (Steele, 1968) give the number of effective nuclei per gram of AgI as shown in Table 2. The last column gives the total number of nuclei produced by the flare.

5. Seeding logistics

As soon as the radar has detected a storm, deemed suitable for a seeding experiment, moving into the experimental area, the seeding aircraft takes off from Namao. The T-33 takes up a holding pattern south of the storm at 30,000 ft. From this vantage point the pilot has an excellent view of the storm and is in a good position to observe the developing cloud towers and advise project control. Once the ground mobile units are in position to sample the rain and hail downwind of the seeding the go-ahead for an experiment is given. In 1970, the University of Wyoming C-45H Twin Beech aircraft participated in the experiments and was used to map the updrafts under the storms and assist in the deployment of the mobile sampling units.

The flight drop altitude is determined from a cumulus convection model (Chisholm, 1970) based on the most recent radiosonde ascent from Rocky Mountain House or Penhold. From this model the height of the -5C level and the updraft profile in the cloud are used along with the known fall distance of the flare in still air, to determine the drop altitude for the day. Flares were dropped every 2 sec or approximately every 1000 ft over the longest dimension of the cumulus towers. After several runs on successive new developments the aircraft returned to a holding pattern and continued to photograph cloud development. The seeding logistics are illustrated schematically in Fig. 6.

A mobile photography unit was deployed to a position, usually to the south of the storm, at a distance of 15–30 mi. Cloud development was recorded on 16-mm movie film with a 3-sec time lapse After each experiment telephone surveys were made of the farmers in the storm path, to solicit information on the precipitation.

6. Turbulence measurements in cumulus towers

Turbulence measurements were made by a second instrumented T-33 aircraft from NAE (Treddenick, 1971). This aircraft accompanied the seeding aircraft on two days and made measurements of longitudinal gust velocities during cloud penetrations. Depending on its length, each run was split into two or three segments. Dissipation rates were then calculated using the values of the longitudinal gust spectrum averaged over each segment.

Table 3 summarizes the results obtained from several penetrations of a small cumulus, cumulus congestus, and a turret on the south of a decaying hailstorm. These results indicate that the value of turbulence dissipation rate in large cumulus towers is of the order 1000 $\mathrm{cm}^2\,\mathrm{sec}^{-3}$ compared to values of less than 10 $\mathrm{cm}^2\,\mathrm{sec}^{-3}$ found in the main updraft core of a hailstorm (Berry, 1970).

Table 3. Summary of turbulence dissipation rates measured in cumulus clouds at 18,000 ft.

Cloud type	Run no.	Dissipation rate ϵ ($\mathrm{cm}^2\,\mathrm{sec}^{-3}$) Segment of traverse 1st	2nd	3rd
Small cumulus	1	49	69	
	2	47	73	25
	3	136	95	
Cumulus congestus	1	269	1148	1314
	2	465	1597	1731
	3	102	669	584
Cumulus tower on decaying hailstorm	1	691	269	81
	2	33	495	125

7. Estimates of seeded volumes and nuclei concentrations

Using the seeding flare output (Table 2) and the turbulence measurements in the previous section, it is possible to obtain an order-of-magnitude estimate of the volume seeded and the nuclei concentration produced. Initially the falling flares produce a silver iodide line source 900 m long (Table 1) which expands with time to produce a seeded cylindrical volume. Using the simplified approach of MacCready and Vickers (1966), the seeded plume diameter d (cm) after a time t (sec) is given by

$$d^2 = C\epsilon t^3, \quad \text{for } t < 1000 \text{ sec}, \tag{1}$$

where ϵ is the turbulent dissipation rate, and C a constant of order unity. Assuming that the seeded plume will also expand in the vertical at a rate given by (1), then the seeded volume can be calculated for various values of ϵ and t. The results for 2 and 5 min after seeding are shown in Table 4. Initially the cloud seeding material is put into the storm between the -5 and -12C levels. After 2 min the nuclei concentration active at -10C is calculated. After 5 min most of the seeding material will have risen to the -15C or higher level and so at this time the concentration effective at -15C is given.

Table 4. Estimates of the seeded volume and ice nuclei concentration produced by a single flare.

	2 min after seeding Plume dimensions				5 min after seeding Plume dimensions			
ϵ ($\mathrm{cm}^2\,\mathrm{sec}^{-3}$)	Diameter (m)	Length (m)	Volume (km^3)	Nuclei conc at -10C (liter^{-1})	Diameter (m)	Length (m)	Volume (km^3)	Nuclei conc at -15C (liter^{-1})
500	290	1190	0.1	2×10^3	1160	2060	2.2	8×10^3
1500	510	1410	0.3	8×10^2	2010	2910	9.2	2×10^3

In the 1970 experiments, flares were dropped approximately 300 m apart. Table 4 shows that under the turbulence conditions expected in the target zone, the plumes from successive flares will be overlapping within 2 min of flare burn-out. After 5 min a substantial cloud volume will be seeded with ice nuclei concentrations at least two orders of magnitude above the maximum natural background found in Alberta (Vali, 1971).

8. Use of chaff in flares

The chaff flares can be used in two ways. As a height marker they are useful for confirming the fall distance when flares are dropped into cumulus towers, since at the time of seeding the towers are not producing radar echo. However, radar reflectivity and polarization measurements are being used as primary tools for evaluation of the experiments. It is therefore undesirable to put too much chaff into a seeded cloud volume, since even a small amount can have a strong effect on the polarization measurements due to the large axial ratio of the chaff. The chaff flares can also be used as plan position markers by dropping them outside the cloud at the beginning and end of the seeding run. The sensitivity of the Alberta Hail Studies radar is such that the chaff bundles in the flares could be detected up to a range of 35–40 mi.

9. Improvements in 1971

Five experiments conducted in 1970 suggested several improvements which were incorporated into the system in 1971. The flare rack was completely rebuilt to increase the capacity to 104 flares. An X-band transponder was mounted in the aircraft and a tracking radar was installed at Penhold. The X-band radar antenna has a vertical beam width of 26° so that the aircraft can be continually tracked except when less than 10 mi from Penhold. The X-band antenna is synchronized with the main weather radar and the aircraft position is indicated on the same radar displays as the weather echoes. The aircraft position relative to the storm is thus accurately known at all times. A supply of flares was kept at Calgary (see Fig. 1) so that the aircraft could land there when working storms in the southern half of the project area. A side-pointing 16-mm movie camera was mounted in the cockpit to take pictures at 4 frames sec^{-1}. Finally the range and bearing from the nearest navigation beacon was recorded on the strip chart as a back-up position-keeping system. A total of 11 experiments were conducted using the improved system in 1971.

10. Conclusions

A droppable pyrotechnic flare system has been successfully adapted for use on a T-33 jet aircraft to seed Alberta hailstorms. Recognition of the new development on the southern flank of mature storms and subsequent seeding proved to be easier than anticipated. The one surprise was the quick reaction time required ($\sim$1 min) between recognition of the new cloud development and the seeding pass. The aircraft speed capability ($\sim$300 kt) is thus considered to be an essential requirement for this type of experimental seeding.

In 1970, by means of radio communication between the aircraft and the project radar control, it was possible to unambiguously identify and seed the target storm. This was made much easier in 1971 using the transponder. The transponder also gave a very reliable fix on the location of the seeding run relative to the storm cloud at ranges out to 100 mi.

This system thus appears to be a very practical one for applying the direct-injection seeding technique to multicellular hailstorms. The system is flexible since the delay fuse could be adjusted to suit different target heights, or required drop altitudes, or both. The seeding rate can be varied by changing the spacing of the flares dropped on a seeding pass, or the amount of the AgI charge.

Calculations of dissipation rates indicate that sufficient diffusion of the silver iodide will occur to produce freezing nuclei concentrations in excess of 100 liter^{-1} through large volumes of cumulus towers within a few minutes of seeding. Experiments are continuing to ascertain whether the seeding concept is valid, whether this particular type of seeding can suppress hail in multicellular storms, and whether the technique can be adapted to seed supercell type storms.

Acknowledgments. The results of the T-33 aircraft measurements are published with the permission of the Director of the National Aeronautical Establishment.

REFERENCES

Battan, L. J., 1969: Weather modification in the U. S. S. R.—1969. *Bull. Amer. Meteor. Soc.*, **50**, 924–945.

Berry, E. X., 1970: A study of hailstorms using airborne radar. Tech. Rept. 13, Lab. Atmos. Physics, Desert Research Inst., University of Nevada System, Reno, 11 pp.

Chisholm, A. J., 1966: Small scale radar structure of Alberta hailstorms. Rept. MW-49, Stormy Weather Group, McGill University, 55–72.

——, 1970: Estimates of the precipitation growth environment in the updraft core of Alberta hailstorms. *Preprints of Papers, Conf. on Cloud Physics*, Fort Collins, Colo., Amer. Meteor. Soc., 151–152.

Dennis, A. S., C. A. Schock and A. Koscielski, 1970: Characteristics of hailstorms in western South Dakota. *J. Appl. Meteor.*,**9**, 127–135.

Henderson, T. J., 1970: Results from a two-year operational hail suppression program in Kenya, East Africa. *Preprints of Papers, Second Nat'l. Conf. Weather Modification*, Santa Barbara, Calif., Amer. Meteor. Soc., 140–144.

Kartsivadze, A. I., 1968: Modification of the hail processes. *Proc. Intern. Conf. Cloud Physics*, Toronto, 778–788.

MacCready, P. B. Jr., and W. W. Vickers, 1966: Hailswath program analysis and hail suppression program planning. Project Hailstop: Final Report. Rept. 66–9, South Dakota School of Mines and Technology, 50 pp.

Marwitz, J. D., and E. X Berry, 1971: The airflow within the weak echo region of an Alberta hailstorm. *J. Appl. Meteor.*, **10**, 487–492.

Picca, R., 1971: An operational method of hail suppression in France. *Preprints of Papers, Intern. Conf. Weather Modification*, Canberra, Australia, Amer. Meteor. Soc., 211–212.

Renick, J. H., 1971: Radar reflectivity profiles of individual cells in a persistent multicellular Alberta hailstorm. *Preprints of Papers, Seventh Severe Local Storms Conf.*, Kansas City, Mo., Amer. Meteor. Soc., 63–70.

Schleusener, R. A., 1968: Hailfall damage suppression by cloud seeding—A review of the evidence. *J. Appl. Meteor.*, **7**, 1004–1011.

——, A. Koscielski, A. S. Dennis and M. R. Schock, 1970: Hail experience on eight project seasons of cloud seeding with silver iodide in the northern Great Plains. *Preprints of Papers, Second Nat'l. Conf. Weather Modification*, Santa Barbara, Calif., Amer. Meteor. Soc., 145–149.

Simpson, J., W. L. Woodley, H. A. Friedman, T. W. Slusher, R. S. Scheffee and R. L. Steele, 1970: An airborne pyrotechnic cloud seeding system and its use. *J. Appl. Meteor.*, **9**, 109–122.

Steele, R. L., 1968: Evaluation of ice nuclei sources and their development: Production and delivery of cloud nucleating materials. *Proc. Skywater Conference III*, Office of Atmospheric Resources, Bureau of Reclamation, Denver, Colo., 51–92.

Sulakvelidze, G. K., 1968: On the principles of hail control method applied in the USSR. *Proc. Intern. Conf. Cloud Physics*, Toronto, 796–803.

Summers, P. W., and A. H. Paul, 1967: Some climatological characteristics of hailfall in central Alberta. *Preprints of Papers, Fifth Conf. Severe Local Storms*, St. Louis, Mo., Amer. Meteor. Soc., 315–324.

——, and J. H. Renick, 1971: Case studies of the physical effects of seeding hailstorms in Alberta. *Preprints of Papers, Intern. Conf. Weather Modification*, Canberra, Australia, Amer. Meteor. Soc., 213–218.

——, and L. Wojtiw, 1971: The economic impact of hail damage in Alberta, Canada and its dependence on various hailfall parameters. *Preprints of Papers, Seventh Severe Local Storms Conf.*, Kansas City, Mo., Amer. Meteor., Soc., 158–163.

Treddenick, D. S., 1971: A comparison of aircraft and Jimsphere wind measurements. *J. Appl. Meteor.*, **10**, 309–312.

Vali, G., 1971: Freezing nucleus content of hail and rain in Alberta. *J. Appl. Meteor.*, **10**, 73–78.