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T-28 PARTICIPATION IN THE 1987 FIELD SEASON OF THE NORTH DAKOTA FEDERAL/STATE COOPERATIVE WEATHER MODIFICATION PROGRAM

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1. INTRODUCTION

There have been operational cloud seeding programs in North Dakota for more than 30 years. The main goal of the operational North Dakota Cloud Modification Project, conducted under State auspices since 1976, has been to reduce hail damage to crops in the western regions of the state. Ice nucleating materials have been released from aircraft into convective clouds which have the potential to produce hail.

The Federal/State Cooperative Program has conducted a program of atmospheric research in conjunction with this operational seeding program during several summer seasons in the 1980's. This research has recently been aimed at (1) an improved understanding of mixing and transport of material released at cloud base into and through clouds, and (2) a determination of how effective the nucleating materials are and where they nucleate ice in treated clouds. The answers sought in these two areas will illuminate the initial links in the chain of events leading to the successful hail suppression results achieved by the operational project (Smith et al., 1987). It is hoped these answers will lead to improved treatment strategies and even better hail suppression results.

The experimental technique developed to conduct this research (Stith et al., 1986) involves multiple aircraft. One releases ice-nucleating and inert-tracer materials into a cloud. One or more additional aircraft perform repeated penetrations of the cloud and make detailed measurements of cloud particle types, sizes, and concentrations and also of tracer concentrations, in various regions of the cloud as it evolves.

Several different types of missions were flown in the 1987 field experiment, almost all of them originally spelled out in the "1987 Research Program Operations Plan." The most common was continuous cloud base release of silver iodide and sulfur hexafluoride tracer into cumulus clouds ranging from a kilometer or two in depth to cumulonimbus-size followed by repeated penetrations of the cloud by one or two cloud physics aircraft. Another common treatment experiment was the so-called "mid-cloud" release in which silver iodide and sulfur hexafluoride were released in a single mid-cloud pass through a cumuliform cloud, followed by repeated penetrations of the cloud by one or two cloud physics aircraft. Other experiments included (1) an attempt to release small iron particles into regions of feeder cells thought to be appropriate for the particles to serve as graupel and hail embryos, followed by an attempt to capture iron-containing graupel and hail incloud as well as collect it on the ground (Knight et al., 1986); (2) a flight by the three project aircraft through an altocumulus complex at the same time it was imaged by a LANDSAT satellite's imaging equipment in order to provide "cloud-truth" data for developing techniques for remote sensing of cloud properties; (3) a release of sulfur hexafluoride from the ground on a day with a well-developed turbulent planetary boundary layer, followed by aircraft transects downwind to investigate the evolution of the plume; and (4) two flights aimed essentially at instrument intercomparison. For several flights, an ammonium carbonate solution rather than silver iodide smoke was released from the seeder aircraft in an attempt to observe the effects of ammonia on ice crystal growth and aggregation in cumulus clouds at temperatures just below freezing. In a few cases, sulfur hexafluoride was released without any accompanying cloud treatment agent to provide the necessary evidence to test whether sulfur hexafluoride release by itself alters cloud behavior.

2. PROJECT AIRCRAFT

The 1987 research program involved three aircraft. The "release" aircraft was a Beechcraft Duke. This twin-reciprocating engine propeller-driven aircraft was supplied by Weather Modification, Inc., of Bowman, North Dakota. It was equipped with two wing-tip burners designed by Bill Carley to burn complex solutions of silver iodide in acetone and water. These burners are of the standard type employed in the operational program and release (mostly) silver iodide smoke at a rate on the order of milligrams per kilometer of flight. The Duke was also fitted with hardware to release sulfur hexafluoride gas on demand. This inert material was carried in pressurized tanks as liquid and rapidly evaporated when released into the atmosphere at rates typically in the range of 100's of grams per kilometer of flight.

Two "cloud physics" aircraft were employed. One was the Cessna Citation II operated by the University of North Dakota. This light twin engine turbofan aircraft is equipped to make detailed _in situ_ measurements of cloud dynamic, thermodynamic, and microphysical properties using standard state-of-the-art instrumentation. It also carried sensitive instrumentation to determine ambient sulfur hexafluoride and ozone concentrations. The sulfur hexafluoride instrumentation (Benner and Lamb, 1985) was supplied by North American Weather Consultants. Based on in-field data review, it appeared to be sensitive to sulfur hexafluoride mixing ratios as low as a few parts per trillion by volume (pptv) with a response time of less than a second. The ozone instrumentation was on loan from the National Center for Atmospheric Research. It was sensitive to parts per billion by volume (ppbv) levels of ozone and had a response time on the order of a few seconds.

The other cloud physics aircraft was the T-28 operated by the South Dakota School of Mines and Technology under a cooperative agreement with the National Science Foundation. In this report, a detailed accounting of this aircraft's operations during the field program will be presented.

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3. T-28 PERSONNEL, INSTRUMENTATION AND DEPLOYMENT

The T-28 went into the field at Dickinson on 7 June with a full complement of support personnel. These are listed in Table 1, along with their nominal duties. All personnel remained in the field for the duration of the project, which ended on 5 July. Shortly after its arrival, the T-28 had sulfur hexafluoride sensing instrumentation installed by Rich Benner and George Wilkerson of North American Weather Consultants. George became an honorary member of the T-28 crew as he spent countless hours throughout the project trying to keep the instrument in the T-28 in operating condition.

TABLE 1

Norm Vine	Pilot
Paul Smith	T-28 Facility Manager
Dennis Musil	Meteorologist and Flight Director
Jon Leigh	Aircraft Mechanic
Gary Johnson	Electrical Engineer
Ken Hartman	Data and Software Management
Andy Detwiler	T-28 Facility Scientist

In order to make space and carrying capacity available for the sulfur hexafluoride instrumentation, the T-28's normal primary data system was removed. All data were recorded on the Particle Measuring Systems, Inc., (PMS) data acquisition system. The PMS system is normally used to record data from the two PMS cloud particle probes and a few of the most important variables that are also recorded on the primary data system. It has only 7 auxiliary channels available for non-PMS probe analog data. There was a need to record more than this number, so it was necessary to prioritize among those variables and record the 7 most important. The data recorded varied from flight to flight due mainly to a varying ability to obtain aircraft position data from other sources from day to day. Position data were highly important but, if they could be obtained from other sources, were not recorded on the PMS data system. Table 2 shows the instrumentation from which

TABLE 2

VARIABLE	INSTRUMENT	RANGE	ACCURACY	RESOLUTION (as recorded)	NOTES
STATIC PRESSURE	ROSEMOUNT 1301-A-4-B	0-15 psi (0-103 kPa)	±.015 psi (±0.1 kPa)	0.0075 psi (0.05 kPa)	
	BALL ENGINEERING EX-210-B (NOT RECORDED)	0-27000 ft (0-8.2 km) MSL	±300 ft (±100 m)	30ft (10 m)	
TOTAL TEMPERATURE	ROSEMOUNT 102AU2AP (NOT RECORDED)	-30 - +30°C	±0.5°C	0.015°C	• Platinum wire • ~2 sec time constant
	NCAR REVERSE FLOW	-30 - +30°C	±0.5°C	0.015°C	• Diode • Several sec time constant
CLOUD WATER AND CLOUD DROPLETS	JOHNSON-WILLIAMS LIQUID WATER CONTENT	0 - 6 g/m^3	±10%	0.003 g/m^3	• Accurate if all droplets have d <30 μm
	PARTICLE MEASURING SYSTEMS, INC. FORWARD SCATTERING SPECTROMETER PROBE	Size ~1 < 45 μm Concentration 0 - ~2000 droplets/ cm^3	±1 size channel in size and ±1% in concentrations at ~50/cm^3	1 size channel	• 15 discrete size channels spread over an adjustable range • Sampling rate 300 cm^3/km • Accuracy of computed liquid water contents ~±20%. Depends on processing.
PRECIPITATION PARTICLE SIZES AND CONCENTRATIONS	WILLIAMSON FOIL IMPACTOR	1 - 20 mm	0.2 mm	0.2 mm	• Sampling rate 1.4 m^3/km
	PARTICLE MEASURING SYSTEMS, INC. 2-D Cloud Probe	Size 30 - 1000 μm	±30 μm	30 μm	• Computed ice and water contents can vary ±50% with processing technique • Sampling rate: 0.1 m^3/km; DAS can accept ~250 particles/sec (2500/km)
	HAIL SPECTROMETER (NOT CARRIED)	Size 4.5 mm - 5.4 cm Concentration 0 - 10/m^3	±1 size class	1 size class	• 14 size classes; images available • Sampling rate 100 m^3/km • Alternates with particle camera

TABLE 2 (continued)

PRECIPITATION PARTICLE SIZES AND CONCENTRATIONS (continued)	NCAR PARTICLE SAMPLER				• A batch sampler, primarily for hailstones • Sampling rate 2.6 m³/km
	CANNON PARTICLE CAMERA (NOT CARRIED)	Size >50 μm	50 μm	50 μm	• Sampling rate ≤2 m³/km • Alternates with hail spectrometer
AIRCRAFT MOTION	NCAR TRUE AIRSPEED COMPUTER	0 - 250 kts (0 - 130 m/s)	±3 kts (±1.5 m/s)	0.125 kt (0.07 m/s)	• True airspeed
	HUMPHREY SA09-D0101-1 VERTICALLY STABLILIZED ACCELEROMETER (NOT RECORDED)	-1 to +3 g's pitch -50° to +50° roll -50° to +50°	0.004 g 0.2° 0.2°	0.001 g 0.15° 0.15°	
	ROSEMOUNT 1301-0-1-B DYNAMIC PRESSURE	-3 to +3 psi (-20 to +20 kPa)	±0.1%	0.003 psi (.02 kPa)	• Indicated airspeed
	GIANNINI 45218YE MANIFOLD PRESSURE	0 to 50 in Hg (0 to 169 kPa)	±2%	0.024 in Hg (0.081 kPa)	• Used in some vertical velocity calculations
	BALL ENGINEERING 101A VARIOMETER	-6000 to +6000 ft/min (-30 to +30 m/sec)	±200 ft/min (±1 m/sec)	6 ft/min (0.03 m/sec)	
AIRCRAFT LOCATION	NARCO NAV-122 VOR	0 - 360°	±2°	0.1°	
	CESSNA 400 DME	0 - 100 nmi (0 - 185 km)	0.1 nmi (185 m)	.05 nmi (90 m)	• Maximum 2 sec to lock on and acquire range

NOTE: Many of these instruments do not behave as ideal instruments. The use of one measure of accuracy over the entire range of measurement is, in many cases, questionable. An accuracy representative of the most useful part of the range is given here.

data were recorded on one or more flights during the field project. The data recorded on any given flight are indicated in Appendix A.

Early in the project, it was presumed that aircraft position data would be obtained by transmitting position information from the Federal Aviation Administration (FAA) tracking radar near Arnegard (about 100 km NNW of Dickinson) to the project meteorological radar computer at Dickinson (the Illinois State Water Survey CHILL radar). When it became clear that this information would not be available until late in the field program, two channels on the PMS data acquisition system were allocated to recording the aircraft's own VOR and DME signals. During the last week of the project, the FAA tracking information was recorded with the CHILL radar data and the two channels were used to record meteorological data, again.

The data were recorded on 9-track magnetic tape. The data format on the tape is given in Appendix A along with a list of the equations used to derive the meteorological quantitites of interest from the raw recorded data.

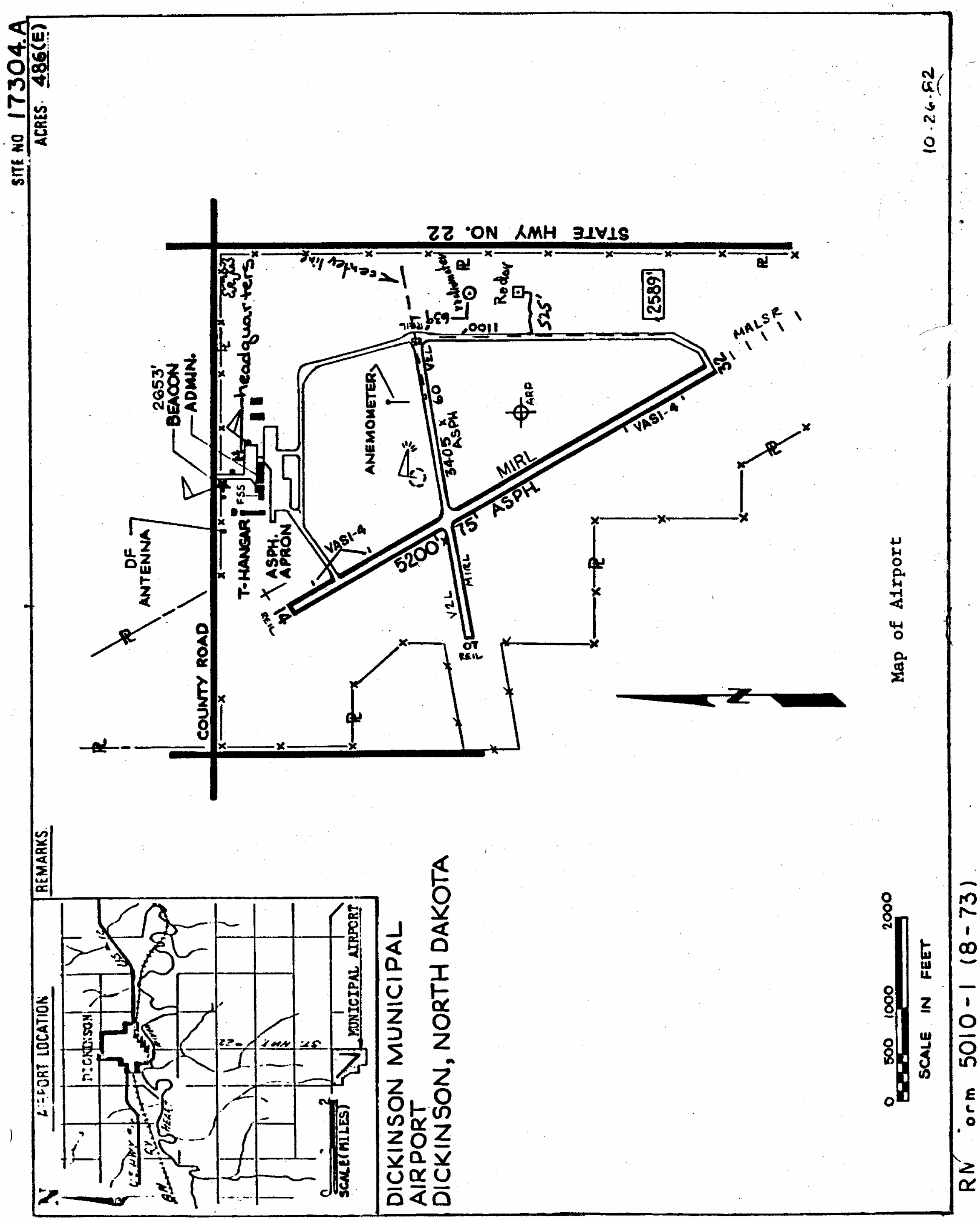
This project represented the first installation of a Benner-Lamb type SF_6 analyzer on an unpressurized aircraft operating to altitudes up to 20,000 ft. The T-28 pilot has no access to data from the PMS recording system in flight, so the aircraft telemetry system was used to transmit the output of the SF_6 analyzer to the ground. This permitted project scientists to examine the detector output in real time, so that they could evaluate the operation of the analyzer as well as direct the flight operations more effectively. The telemetry ground station was installed in the CHILL radar operations van.

The layout of the Dickinson Airport area is shown in Figure 1. The two cloud physics aircraft were quartered in a different hangar than the release aircraft to avoid saturation of the sensitive sulfur hexafluoride detectors in the cloud physics aircraft with tiny amounts of sulfur hexafluoride leaking from the release aircraft. The CHILL meteorological radar was located alongside State Highway 22 near the middle of the taxiway running from the terminal apron to the south end of the SE-NW main runway. The Dickinson VORTAC was located about 6 km NE of the airfield. The coordinates of the radar and VORTAC were:

Radar: 46 deg, 47 min, 48 sec N
102 deg, 47 min, 59 sec W

VORTAC: 46 deg, 51 min, 36 sec N
102 deg, 46 min, 23 sec W

FIGURE 1



Map of Airport

4. FLIGHT OPERATIONS

The T-28 had the least operating range and flight duration of the three project aircraft, and the intent was to concentrate its use on the more mature clouds. The normal mission usually began with the launch of either the Duke or Citation, or both, to do some initial reconnaissance of the situation, and perhaps an initial experiment or two. If it was determined that clouds of sufficient stature were available, the T-28 was called up and a coordinated cloud study involving the three aircraft was attempted.

In some cases, cloud development was judged insufficient to warrant the use of three aircraft and, as a result, the T-28 accumulated the fewest flight hours of the three project aircraft. T-28 flights were conducted on 10 different days from Dickinson. On half of these days, the flights could be categorized as instrumentation test flights (mainly connected with the operation of the sulfur hexafluoride measuring instrumentation), and on the other half the flights were conducted mainly as cloud research flights. Table 3 gives a summary of T-28 flight activity, including a pre-season flight to Salt Lake City for a prefitting of the North American Weather Consultants sulfur hexafluoride equipment and the ferry flights between Rapid City and Dickinson.

A day-by-day summary of each day's flight operations during the field project follows.

9 June:

Take off:	16:50 MDT
Land:	17:40

All three project aircraft went up basically for a checkout flight. At one point in the flight, all three aircraft lined up in-trail at an altitude of 9,000 ft MSL near Medora, approximately 30 n mi west of Dickinson. The leading aircraft, the Duke, released sulfur hexafluoride, and the T-28 and Citation, following behind it in that order, successfully detected the gas with on-board detectors. T-28 temperature and pressure measurements matched those on the other aircraft reasonably well.

Telemetry of the T-28 sulfur hexafluoride detector signal to the ground did not function properly on this flight, although the same data were recorded on the aircraft data system flawlessly. The T-28 FSSP was not on for this flight. No aircraft position data were recorded.

TABLE 3

T-28 FLIGHT SUMMARY

NORTH DAKOTA FEDERAL/STATE COOPERATIVE PROGRAM
DICKINSON, NORTH DAKOTA—1987

DATE	FLT. NO.	TIMES (MDT) T.O.	TIMES (MDT) LND	FLIGHT TIME DURATION (h)	REMARKS
5/18	466			1.9	RAP to Rock Springs
	467			1.4	Rock Springs to SLC for VOR repair and SF_6 instrument installation
5/26	468			1.7	SLC to Casper
	469			1.0	Casper to RAP
6/7	470			1.4	Ferry to DIK
6/9	471	16:50	17:40	1.3	In-trail test
6/13	472	15:21	16:54	1.8	Sniffer test
6/14	473	10:25	11:25	1.3	Sniffer test
6/16	474	14:04	15:48	2.1	Research
6/18	475	16:19	17:56	2.0	Research
6/19	476	14:17	15:55	1.9	Ground relase of SF_6
6/22	477	5:45	7:45	2.0	Tower fly-by
	478	10:40	11:15	1.0	LANDSAT "ground truth"
6/28	479	15:54	17:24	1.7	Research
6/29	480	14:18	15:49	1.9	Research
7/4	481	14:45	16:30	2.0	Research
7/5	482			1.1	Ferry home to RAP
		TOTAL FLIGHT TIME		27.5	

"Flight time" includes taxi time, engine run-up, etc.

13 June:

Takeoff: 15:21
Land: 16:54

The mission for this flight was to test the sulfur hexafluoride detector on-board. Calibration gas mixtures were injected into the instrument from inside the cockpit by the pilot. The instrument worked well until the aircraft climbed above 12,000 ft MSL. Above this altitude, large signal oscillations appeared. Telemetry of the sulfur hexafluoride detector signal to the ground worked well out to a range of 60 n mi.

Other project aircraft did not fly. No clouds were penetrated. No aircraft position data were recorded. The FSSP was back on the aircraft for the rest of the season.

14 June:

Takeoff: 10:25
Land: 11:25

Another test of the sulfur hexafluoride instrument, after some adjustments, was performed with on-board injection of calibration gas mixtures. The instrument was functional at 15,000 ft MSL, but not at 20,000 ft MSL. Above 15,000 ft MSL, large oscillations appeared in the detector signal that were thought to be due to changes in hydrogen flow through the combustion chamber of the unit. The flight was done VFR in clear air. A strong telemetry signal was received by the ground flight director throughout the flight, using a receiving antenna atop the CHILL radome.

The sulfur hexafluoride data were not recorded on-board because of a bad connection to the aircraft data acquisition system. No aircraft track information was recorded. Other project aircraft did not fly.

16 June:

Takeoff: 14:04
Land: 15:48

The T-28 followed the two other project aircraft out and participated in coordinated penetrations of a line of developing cumulus cells northwest of Dickinson. At the time of the penetrations, cloud bases were near 12,000 ft MSL and cloud tops at 19,000 MSL. The T-28 penetrations were at 16,000 ft MSL, above the Duke, releasing sulfur hexafluoride gas and silver iodide smoke at cloud base, and below the Citation near cloud top. These clouds developed rapidly and, after a time, the parent storm took on a "supercell" character in which there was one main storm core with no feeder cells.

When the two other aircraft headed to the southwest of Dickinson to look for more workable clouds, the T-28 returned to Dickinson due to lack of fuel.

Aircraft track data were recorded on-board during this flight. No sulfur hexafluoride plumes were detected; the sulfur hexafluoride sample intake tube worked itself loose from the sample inlet at some point during the flight. The foil impactor blew a circuit breaker and no data were obtained from it. The 2D-C probe was acting flaky and the data from it are marginal, most buffers being full of "zero-element" images. A sample of graupel or small hail was obtained in the NCAR "hail catcher" (developed by Nancy Knight and Walter Grotewold) during one penetration, but it had melted by the time the sampler was opened on the ground.

18 June:

Takeoff:	16:19
Land:	17:56

The three project aircraft rendezvoused over Medora (west of Dickinson) to do a series of coordinated release/penetrations in towering cumulus clouds. (The Duke and Citation had previously worked a small cloud SW of Dickinson.) Visual coordination was difficult because there was much mid-level cloudiness and multiple updrafts. They began working a cloud near 309 deg/25 n mi (relative to Dickinson VORTAC) around 16:55. The T-28 was again penetrating at mid-cloud levels above the Duke and below the Citation. The situation was confused enough that the participants were not sure, after the fact, if they had all, indeed, been working the same cloud. T-28 continued to work the same area for a time after the other two aircraft left to look for more exciting clouds.

The T-28 had recorded on-board flight track information. No sulfur hexafluoride plumes were detected.

19 June:

Takeoff:	14:17
Land:	15:55

The Duke was not available on this day due to fuel pump problems. The T-28 and Citation traversed Dickinson VORTAC, at 5 n mi and 10 n mi ranges, respectively, and at altitudes from 1,000 ft to 3,000 ft AGL, while sulfur hexafluoride was released from the VORTAC site itself, at the ground. Sulfur hexafluoride was detected by both aircraft at nearly the same radial position and at similar concentrations. The T-28 later climbed out to higher altitudes for checks of the (further modified) SF_6 detector. At 15,500 ft MSL, the oscillations corresponded to about 100 ppt peak amplitude, and they seemed a little smaller at 17,500 ft.

22 June:

Takeoff:	5:45
Land:	7:45

Tower fly-by exercise at Bowman was performed. T-28 reverse-flow temperatures were consistently about 2°C lower than "tower" temperatures. A new temperature equation was worked out based on this exercise and all temperature data for this project have been reduced using this new equation.

22 June:

Takeoff:	10:40
Land:	11:15

The T-28 flew through altocumulus clouds near Medora on the return trip from Bowman to Dickinson in order to get "ground truth" cloud microphysical data for analysis of radiative properties of clouds imaged simultaneously by LANDSAT. The -12°C clouds contained very little supercooled water and beautiful snow crystals.

Flight track data were recorded on-board. All instrumentation worked well. T-28 cloud particle, temperature, and pressure data compared well with those of the other two aircraft.

28 June:

Takeoff:	15:54
Land:	17:24

The T-28 participated in coordinated cloud-base release/ penetrations in a towering cumulus west of Dickinson near the Montana border. The other two aircraft had previously treated two other clouds. Aircraft coordination went well. Sulfur hexafluoride plumes were detected by both the T-28 and Citation in this cloud. The cloud developed an echo aloft about 20 min after treatment began. One of the clouds in the study area later developed into a large cumulonimbus cloud.

This was the first project flight for which real-time flight track information was available to ground personnel at the radar site. Tracks were not recorded with the radar data, however. All aircraft had on-board recording of flight tracks. T-28 instrumentation worked well except for an intermittent noise problem in the recorded value of static pressure which rendered the calculation of vertical winds useless. Both the Citation and the T-28 picked up a lot of ice.

29 June:

Takeoff: 14:18
Land: 15:49

Clouds were icing out and collapsing by the time the T-28 joined the other two project aircraft southwest of Dickinson. Coordinated release/penetrations were done on relatively thin clouds; there was barely room for three aircraft to stack vertically between cloud base and top. Updrafts were weak and incoherent. No sulfur hexafluoride plumes were detected by the T-28.

Late in the flight, the T-28 broke away from the other two aircraft and climbed in clear air to test the response of the sulfur hexafluoride detector to reduced ambient pressure. The instrument signal started to oscillate again at around 14,000 ft MSL.

FAA aircraft tracks were recorded with CHILL radar data during this flight. T-28 instrumentation worked well.

4 July:

Takeoff: 14:45
Land: 16:30

Project aircraft worked an area of explosive cloud development northwest of Dickinson. At first, the Duke and Citation attempted a cloud base release of sulfur hexafluoride and ammonium carbonate. The second experiment was a release by the Duke of iron powder at about 18,000 ft MSL in the upper portion of a towering cumulus cloud with the T-28 penetrating simultaneously 1,000 ft above. After the Duke cleared the cloud, the T-28 descended to 18,000 ft and made several penetrations. In the meantime, the other project aircraft went off to work another area.

The T-28 eventually joined the other aircraft near Beach and they attempted to make a coordinated sulfur hexafluoride/silver iodide cloud-base release/penetration study on a line of feeder cells near a big storm. Low fuel supply forced the T-28 at 13,000 ft, just above the Duke, to return to Dickinson after the first penetration, so there was not time to repenetrate and look for sulfur hexafluoride or ice crystal plumes.

Some of the iron powder release cartridge devices did not function properly during the first study of the mission. Also, after the mission, the consensus was that the clouds penetrated during the second 3-aircraft experiment were not really feeder cells.

T-28 instrumentation worked well except for some problems early in the flight with the JW liquid water content meter. FAA flight tracks were recorded with CHILL radar data.

Weather briefing summaries for the 5 days with penetrations of active convective clouds are presented in Appendix B.

Voice notes recorded during each flight by the pilot are transcribed and presented in Appendix C.

5. DATA SURVEY

A survey of the data collected on the 6 flights with cloud penetration data is given in Table 4. The table is organized by date and penetration, listing times, positions, and extreme values of vertical winds, droplet concentrations, precipitation particle concentrations, etc., encountered on each penetration.

The most interesting study of the project in which the T-28 participated occurred on 28 June. The three aircraft coordinated well on one particular cloud that developed precipitation as it was being studied. The T-28 data quality for this day is very good except for the static pressure. Unfortunately, the noise in the static pressure data makes the calculated pressure altitude fluctuate dramatically from one second to the next and renders any reasonable attempt at an updraft calculation fruitless.

Another interesting study of which the T-28 was part occurred on 22 June as all three project aircraft penetrated an altocumulus complex as a LANDSAT imaged it from overhead. All three aircraft collected good quality data. The LANDSAT thematic mapper data was unavailable for this particular image, but multispectral scanner data (lower resolution than the thematic mapper) are available.

The data on the remaining four days listed in Table 4 are of mixed quality for various reasons. Aircraft coordination was generally not as good and the clouds not as well surveyed on these days. The clouds on 18 June and 29 June were relatively weak. Those on 16 June and 4 July were relatively intense. The 2D-C cloud particle shadowing probe had a noise problem on 16 and 18 June and 4 July which inserted a lot of useless data into the data stream. The "real" particle shadows can be analyzed with some extra effort.

The observations from the 19 June ground release test, although not listed in Table 4, also appear to be of scientific interest. The successful interception of the SF_6 plume by the two aircraft at different distances from the source provides a particularly useful data set.

TABLE 4

Summary of T-28 Cloud Penetration Data

Date	Flt	Pen #	Beg Time (MDT)	End Time	Heading (mag.)	Mdpt Lat (deg N)	Mdpt Lon (deg W)	Pen. len. (km)	Cloud Base(m)	Cld Bse T(C)	Pen. alt. (m)	Pen. T(C)
16 Jun	474	1	144556	144723	90	46 45	102 45	10	3500	6	5000	-6
cloud bse	release	2	145158	145300	265	46 45	102 45	7	3500	6	5000	-6
		3	145355	145426	120	46 45	102 45	3	3500	6	5000	-6
		4	150255	150340	300?	46 50	102 53	5	3500	6	5000	-6
18 Jun	475	1	165045	165100	110	47 00	103 25	2	3000	6	5000	-6
cloud bse	release	2	170630	170750	325	47 15	103 06	8	3000	6	5000	-6
		3	171510	171600	150	47 20	102 53	5	3000	6	5000	-6
		4	172053	172143	330	47 20	102 47	5	3000	6	5000	-7
		5	172455	172600	150	47 20	102 47	7	3000	6	5000	-7
		6	173020	173045	330	47 20	102 46	3	3000	6	5000	-8
		7	173405	173438	145	47 20	102 46	3	3000	6	5000	-8
		8	174155	174220	150	47 20	102 45	3	3000	6	5000	-8
22 Jun	478	1	110500	111200	100	47 03	103 18	40			5880	-12
satellite	underpass											
28 Jun	479	1	162037	162132	340	46 53	103 53	5	2500	6	3000	2
cloud bse	release	2	162407	162508	130	46 53	103 52	6	2500	6	3000	1
		3	162645	162844	270	46 48	103 50	11	2500	6	3200	-1
		4	163005	163237	100	46 48	103 48	14	2500	6	3500	-2
		5	163500	163730	255	46 43	103 43	14	2500	6	3600	-2
		6	164055	164227	65	46 47	103 40	14	2500	6	4000	-4
		7	164500	164753	270	46 44	103 35	16	2500	6	4300	-6
		8	165020	165202	100	46 42	103 33	9	2500	6	4300	-6
		9	165400	165639	250	46 36	103 27	15	2500	6	4300	-6
		10	165801	170004	80	46 36	103 27	11	2500	6	4300	-6
29 Jun	480	1	150250	150325	180	46 34	103 25	3	2000	7	2400	4
mid-cloud	release	2	150530	150600	35	46 34	103 25	3	2000	7	2500	4
		3	150935	151005	215	46 34	103 25	3	2000	7	2750	[illegible]
		4	151217	151237	360?	46 33	103 23	2	2000	7	3000	0
		5	151608	151622	180?	46 36	103 17	1	2000	7	2500	3
		6	151950	152008	115	46 33	103 13	2	2000	7	2750	2
		7	152215	152227	295	46 33	103 13	1	2000	7	3000	0
		8	152255	152315	295	46 36	103 17	2	2000	7	3000	0
		9	152608	152617	115	46 36	103 17	1	2000	7	3000	0
		10	152642	152702	115	46 33	103 13	2	2000	7	3000	0
4 Jul	481	1	151409	151516	42	46 36	103 43	7	3000	9	5800	-12
iron powder	release	2	152020	152131	235	46 35	103 42	8	3000	9	5800	-12
	(md cld)	3	152502	152627	55	46 38	103 38	9	3000	9	5800	-12
		4	152914	153115	240	46 36	103 37	13	3000	9	5800	-12
		5	153529	153647	50	46 36	103 37	8	3000	9	5800	-12
		6	154003	154142	270	46 36	103 42	11	3000	9	5800	-12
		7	154346	154544	50	46 36	103 40	13	3000	9	5800	-12
cloudbase	release	8	161140	161348	100	46 56	103 48	13	3000	9	4000	-1

TABLE 4 (continued)

Pen. Ht. abv base (m)	Wmax (m/s)	Wmin (m/s)	Max LWC FSSP(g/m3) (1 sec)	Adiabatic LWC(g/m3)	Max LWC/ Adb. LWC	Max Conc FSSP(/cc) (1 sec)	Mean Dia FSSP(um)	Max Conc 2D-C(/l) (1 sec)	Max Dia 2D-C(um)	SF6 (ppt)
1500	18	-6	1.40	1.86	0.75	702	14	640	2000	
1500	13	-13	1.80	1.61	1.12	797	14	254	1500	
1500	3	-14	1.50	1.65	0.91	748	14	33	1000	
1500	3	-13	0.70	0.74	0.95	605	11			
2000	0	-3	0.10	2.17	0.05	520	5			
2000	6	-6	1.10	2.20	0.50	730	12	85	3000	
2000	0	-6	0.70	2.20	0.32	690	11		1500	
2000	3	-4	0.70	2.20	0.32	588	11		1500	
2000	3	-6	0.60	2.20	0.27	667	8	3	2000	
2000	2	-4	0.20	2.20	0.09	578	7		2000	
2000	4	-6	0.40	2.20	0.18	542	9		3000	
2000	0	-3	0.20	2.20	0.09	566	7		1500	
	3	-3	0.80			180		30	6000	
500			0.40	0.27	1.48	338	11			
500			0.20	0.40	0.50	282	7			
700			0.50	0.35	1.43	344	12			200
1000			0.60	0.88	0.68	374	13	3		400
1100			0.50	0.80	0.63	307	13			400
1500			0.60	1.68	0.36	279	14	135	1000	200
1800			0.70	1.98	0.35	299	14	10	1500	
1800			0.60	1.70	0.35	297	14	36	3000	100?
1800			0.50	1.70	0.29	260	14	118	3000	
1800			0.50	1.90	0.26	229	14	30	1000	
400	8	0	0.20	0.76	0.26	234	11		600	
500	8	-3	0.30	0.95	0.32	236	11		600	
750	4	-2	0.30	1.14	0.26	183	12		600	
1000	3	-4	0.20	1.71	0.12	132	13		600	
500	5	2	0.00	0.95	0.00	160	7		600	
750	5	0	0.10	1.14	0.09	126	7		600	
1000	4	1	0.10	1.71	0.06	105	8		600	
1000	3	0	0.10	1.71	0.06	119	11		600	
1000	5	0	0.10	1.71	0.06	70	11		600	
1000	4	0	0.10	1.71	0.06	118	10		600	
2800	3	-5	0.70	2.90	0.24	289	15	580	1800	
2800	5	-3	0.80	2.90	0.28	288	16	590	1400	
2800	4	-4	0.10	2.90	0.03	80	21	1077	1800	
2800	5	-10	0.40	2.90	0.14	150	15	235	1300	
2800	7	-5	0.60	2.90	0.21	199	16	64	1300	
2800	4	-8	0.10	2.90	0.03	36	14	494	1500	
2800	6	-6	0.30	2.90	0.10	126	14		1500	
1000	10	-3	0.40	1.20	0.33	423	11		1500	

6. INVESTIGATIONS UNDERWAY

T-28 facility personnel are currently working with Jeff Stith, of the University of North Dakota, on a case study of the 28 June cloud-base release case mentioned above. A paper will be presented at the International Cloud Physics Conference this summer by Jeff concerning results of this study (Stith et al., 1988).

Mike Huston, a Department of Meteorology graduate student at the South Dakota School of Mines and Technology, is working on a comparison between cloud model predictions for the 28 June case and actual observations. He will also look at a comparison between radar observations of this cloud and in situ aircraft measurements.

Andy Detwiler is looking at various aspects of the distribution of precipitation in the clouds studied during the 1987 field program. He has also worked some of the observations into a comparison of in situ cloud observations obtained in the various geographic regions in which the T-28 has flown over the years (Detwiler, 1988).

7. ACKNOWLEDGMENTS

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8. REFERENCES

Benner, R. L., and B. Lamb, 1985: A fast response continuous analyzer for halogenated atmospheric tracers. J. Atmos. Ocean Tech., 2, 582-589.

Detwiler, A. G., 1988: Geographic variation of severe storm microphysics and dynamics. Preprints 15th Conf. Severe Local Storms, Baltimore, MD, Amer. Meteor. Soc., --.

Knight, N. C., A. J. Weinheimer and M. B. Steiner, 1986: The use of powdered iron as a tracer in hailstorm research. Preprints Joint Sessions 23rd Conf. Radar Meteor. and Conf. Cloud Physics, Snowmass, CO, Amer. Meteor. Soc., JP1-JP2.

Smith, P. L., J. R. Miller, Jr., R. L. Rose and P. W. Mielke, Jr., 1987: An exploratory study of North Dakota crop-hail insurance data for evidence of seeding effects. Preprints 11th Conf. Wea. Modif., Edmonton, Alberta, Canada, Amer. Meteor. Soc., 86-89.

Stith, J. S., D. A. Griffith, R. L. Rose, J. A. Flueck, J. R. Miller, Jr., and P. L. Smith, 1986: Aircraft observations of transport and diffusion in cumulus clouds. J. Climate Appl. Meteor., 25, 1959-1970.

Stith, J. L., M. K. Politovich, R. F. Reinking, A. Detwiler and P. L. Smith, 1988: Investigating mixing and the activation of ice with gaseous tracer techniques. Proc. 10th Intnl. Cloud Physics Conf., 15-20 Aug 1988, Bad Hamburg, Germany.

APPENDIX A: DATA FILES AND FORMATS

The data tapes for the Dickinson 1987 field season, flights 471-481, are located on the lowest shelf of the tape rack nearest the line printer in the IAS computer room. The tapes have handwritten labels of PMS471, PMS472, etc. There is no "magnetic" tape label.

The reduced data files are located on directory [HARTMAN.T28] on the IAS VAX minicomputer system. They have file names PMSflt.RED (e.g., PMS479.RED). Flight 477 was not reduced here on the VAX; it was the tower flyby at Bowman. All the other flights (that is, the .RED files) have been backed up onto a multifile saveset tape which is kept in Ken Hartman's office. The particular saveset (BACKUP terminology) for Dickinson data is the 6th one on tape. It is labelled MUAO:DICK.FIL.

<u>Note concerning "raw" data tapes</u>:

The slow record 16-bit words represent binary coded decimals (which differ from a strictly binary format) in the range 0-9999. Each decimal is represented by a 4-bit field. The subroutine BCD, stored on file [HARTMAN.T28] V_SUB$BCD.FOR, is used by data reduction programs to interpret the numeric value.

Dickinson data reduction report

The PMS data tapes have been reduced with the procedure file [HARTMAN.T28.DICK]REDUCE_PMS.COM. The resultant reduced data files are stored on their parent directory, [HARTMAN.T28].

Each data record consists of 55 floating point values. Some of the variables, and their position in the 55-word array (x), are listed below: (Raw means the converted BCD value.)

```
 x(2) -- True air speed; 0.0325* Raw(1)

x(10) -- Static pressure; 0.1033251* Raw(21) + 11.82551

x(11) -- Altitude; 4.43077E4* (1.0-(StatPr/1013.3027)** 0.190284

x(12) -- Dynamic pres; 0.02079* (Raw(22) - 41.4054)

x(22) -- Indicated air speed;
         SqRt(5.79E5*((1. + DynPr/1013.3027)**0.28571 - 1.))

x(13) -- Reverse Flow Temp, uses following algorithm
         PrRatio = 1. + DynPr/StatPr
         RMACH2 = 5. + (PrRatio**.2857 1- 1.)
         URFT = -28.0 + 0.005806* Raw(14)
         RFT = (URFT + 273.16)/(1. + 0.126*RMACH2) -273.16

x(14) -- Manifold pres; 6.0856E-3*Raw(15)
```

x(21) -- Updraft; uses an involved algorithm based on the so-called "Cooper" method. (See Kopp, J. Atmos. Ocean. Tech., 2, pp 684-688, 1984).

```
         U1 = 10-sec av. altitude change
         U2 = (27.0 - average manifold pres) *92.0
         U3 = (average indicated air speed*1.94254 - 140.) *17.7
         RFTUC = URFT + 273.16
         RFTCF = 1.0 + 0.126*RMACH2
         UPDR = U1 + (U2 + U3) * 0.00508
         TAS = SQRT(RFTUC*(RMACH2*401.856)/RFTCF)
         x(20) = (TAS*(TAS - previous TAS))/9.775
         Updraft = UPDR + 10-sec avg of x(20)
```

x(3) -- SF_6; raw BCD values ranging from 0-9999 correspond to voltage range of 0 to 5. When display data procedure is run, the user has the option of entering voltage equivalent and concentration pairs from the calibration done before and/or after the specific flight. These values are used by a least squares routine to generate a linear equation which converts raw counts to parts per trillion.

x(4) -- For flights 471-473 and 481, J.W. was recorded
J.W. = 1.2E-3 *(Raw(20)-5000.)
For flights 474-480, VOR was recorded
VOR = (Raw(20)-5000.)/13.88889

x(5) -- For flights 471-473, rate of climb was recorded
If raw (19) < 6930, ROC = (1.13*Raw(19)-5641.)*.00508
If raw (19) > 6930, ROC = (1.471*Raw(19)-8004.)*.00508
For flights 474-480, DME was recorded
DME = .0183099*Raw(19) - 91.1691
For flight 481, second static pressure was recorded
STAT PR = .1033251*Raw(19)+11. 82551

FSSP Variables

x(31) ... x(45) -- 15 FSSP category counts, 3μm to 45μm, step 3μm
x(31) = Raw (2)
x(32) = Raw (3)
.
.
.
X(37) = Raw (8)
x(38),x(39) = ½*Raw(9)
x(40),x(41) = ½*Raw(10)
x(42),x(43) = ½*Raw(11)
x(44),x(45) = ½*Raw(12)

x(28) - activity; Raw(13)/10.
Effective FSSP beam area is a product of beam diameter, depth of field, and velocity acceptance ratio. We were given the value of 0.229 mm^2 following repairs to the probe by PMS early in the season. Thus,
Sample Volume = 0.229*TAS*1.E-6 m^3

x(29) = ((total particle volume)/(sample volume*1.E3))/(1.-(.55*x(28)/100.))

x(30) - Concentration of particles; total counts/(1.-(.55*x(28)/(100.))

2D-C Probe

The diode resolution was 32 μm, making the total beam diameter 1,024 μm. The depth of field equations used are those provided by Heymsfield and Parrish (NCAR Tech. Note TN-137-IA, 1979). For a He-Ne laser, DF = 2.37E-4*Diameter_of_ Particle**2. The maximum DF is limited to 6.1 cm, which occurs for particles larger than 160 μm. The effective sample area equations vary depending upon the acceptance criterion employed, e.g., center-in, all-in, or fractionally in.

PMS
SLOW DATA RECORD FORMAT

Word #	Contents
1	HEADER 1
2	HEADER 2
3 - 34	Sub-record 0
35 - 66	Sub-record 1
67 - 98	Sub-record 2
99 - 130	Sub-record 3
131 - 162	Sub-record 4
163 - 194	Sub-record 5
195 - 226	Sub-record 6
227 - 258	Sub-record 7
259 - 290	Sub-record 8
291 - 322	Sub-record 9

HEADER 1 = ~ elapsed time at tend of buffer
HEADER 2 = ?
Sub-record = 1 second record

PMS
1 SECOND SUB-RECORD FORMAT

Word #	Contents
1	TAS frequency
2	FSSP chan 1
3	FSSP chan 2
4	FSSP chan 3
5	FSSP chan 4
6	FSSP chan 5
7	FSSP chan 6
8	FSSP chan 7
9	FSSP chan 8+9
10	FSSP chan 10+11
11	FSSP chan 12+13
12	FSSP chan 14+15
13	FSSP activity
14	Rev-flow temp
15	Manifold press
16	End 1 End 2
17	Elapsed seconds
18	Acceleration SF_6
19	Rate of climb
20	J.W. liquid water
21	Pressure x 1

Each 16-bit word contains BCD data; that is, 4 4-bit numeric representations.

PMS
2D IMAGE RECORD FORMAT

Word #	Contents
1	Seconds
2	Milliseconds
3	Slice 1 (high)
4	Slice 1 (low)
5	Slice 2 (high)
6	Slice 2 (low)
.	
.	
.	
.	
.	
2049	Slice 1024 (high)
2050	Slice 1024 (low)

Each "word" is 16 bits.

Word #	Byte #	7	6	5	4	3	2	1	0
1	1	x8000	x4000	x2000	x1000	x800	x400	x200	x100
1	2	x80	x40	x20	x10	x8	x4	x2	x1
2	3	x800	x400	x200	x100	x80	x40	x20	x10
2	4	x8	x4	x2	x1	?	***?	**?	*?
3	5	32	31	30	29	28	27	26	25
3	6	24	23	22	21	20	19	18	17
4	7	16	15	14	13	12	11	10	9
4	8	8	7	6	5	4	3	2	1

* Supposedly 0 for 2DC, 1 for 2DP
** Supposedly 0 for no ovld of 2DC, 1 for ovld
*** Supposedly 0 for no ovld of 2DP, 1 for ovld

APPENDIX B

WEATHER FORECAST SHEETS FOR KEY OPERATIONAL DAYS

6/16/87

DATE/TIME:	1200Z ANALYSIS			0000Z FORECAST		
SOUNDING PARAMETERS	BIS	GGW	RAP	BIS	GGW	RAP
500 mb TEMP (oC)	-9.7	-9.9	-10.7			
TOTAL TOTALS	50.4	48.8	52.6			
K INDEX	36.9	26.9	31.9			
SWEAT INDEX	236	136	211			
LIFTED INDEX	-1	-2	-4	ANALYZED WINDS		
WET BULB 0 (KFT)				KFT	DD	FF kts
0 oC HEIGHT (KFT)	14.5	14.5	14.5	2	145	18
-5 oC HEIGHT (KFT)	16	16	17	4	185	39
-10 oC HEIGHT (KFT)	19	18.5	18	6	180	36
TROP HEIGHT (KFT)	—	—	—	8	165	23
EXPCTD HT. OF FREE CONVECTION (KFT)	35	38.5	38.5	10	160	19
CCL (KFT)	11.5	13	13	12	180	22
Tc (oF)	96	97	95	14	200	22
Tmax (oF) (forecast)	92		89	16	180	11
700 mb T-Td	4	12	10	20	205	9
LOW-LVL MOISTR (g/kg)	8.9	8.3	8.4	FLOOD	DIST I	DIST II
PCBL. WATER (in.)	1.24	.46	.97	(in.)		

GREAT PLAINS CLOUD MODEL

NATURAL / MODIFIED	BIS CLOUD TOP kft	BIS CLOUD TOP oC	BIS MAX UPDFT m/s	GGW CLOUD TOP kft	GGW CLOUD TOP oC	GGW MAX UPDFT m/s	RAP CLOUD TOP kft	RAP CLOUD TOP oC	RAP MAX UPDFT m/s
1.0 km									
2.0 km									
3.0 km									

WORD FORECAST: 500 mb SW expected to move across the area afternoon. ☈ ~~dev~~ developing along cold front in eastern Montana. Possibility of some ☈ tomorrow behind cold front.

SFN 11811

6/18/87

SOUNDING PARAMETERS	BIS	GGW	RAP	BIS	GGW	RAP
500 mb TEMP (oC)	-13.3	-13.9	-12.3			
TOTAL TOTALS	50.6	48.2	47.2			
K INDEX	32.3	27.3	20.9			
SWEAT INDEX	117	66.4	85.9			
LIFTED INDEX	-3.2	-.5	-2.0	ANALYZED WINDS		
WET BULB 0 (KFT)				KFT	DD	FF kts
0 oC HEIGHT (KFT)	13	12	13.5	3	50	6
-5 oC HEIGHT (KFT)	16	14	15.5	6	280	10
-10 oC HEIGHT (KFT)	17	17	17	8	295	14
TROP HEIGHT (KFT)	53+	53	53+	12	330	13
EXPCTD HT. OF FREE CONVECTION (KFT)	33	29	38.5	14	340	13
CCL (KFT)	10	11.5	11.5	16	245	12
Tc (oF)	88	86	90	20	235	17
Tmax (oF) (forecast)	88		88	23	255	12
700 mb T-Td	5	7	13	25	250	31
LOW-LVL MOISTR (g/kg)	9.3	6.6	6.8	FLOOD	DIST I	DIST II
PCBL. WATER (in.)	.83	.78	.67	(in.)		

GREAT PLAINS CLOUD MODEL

NATURAL / MODIFIED	BIS CLOUD TOP kft	BIS CLOUD TOP oC	BIS MAX UPDFT m/s	GGW CLOUD TOP kft	GGW CLOUD TOP oC	GGW MAX UPDFT m/s	RAP CLOUD TOP kft	RAP CLOUD TOP oC	RAP MAX UPDFT m/s
1.0 km									
2.0 km									
3.0 km									

WORD FORECAST: Stability indices indicate a somewhat unstable sounding. Only lifting mechanism present is convergent area over WY, along warm front. Cumulus developing with scattered TSTMS over western No Dak.

SFN 11811

6/28/87

DATE/TIME:	1200Z ANALYSIS			0000Z FORECAST		
SOUNDING PARAMETERS	BIS	GGW	RAP	BIS	GGW	RAP
500 mb TEMP (oC)	-14.1	-13.7	-10.9			
TOTAL TOTALS	49.4	48.8	44.4			
K INDEX	30.3	33.1	21.5			
SWEAT INDEX	82.3	89.3	52.5			
LIFTED INDEX	-3.5	-2.6	.6	ANALYZED WINDS		
WET BULB 0 (KFT)				KFT	DD	FF kts
0 oC HEIGHT (KFT)	12	11.5	13.5	3	335	20
-5 oC HEIGHT (KFT)	14.5	13.5	16	5	305	20
-10 oC HEIGHT (KFT)	16.5	16	17.5	7	285	24
TROP HEIGHT (KFT)	39.5	35.5	39.5	9	290	22
EXPCTD HT. OF FREE CONVECTION (KFT)	35.5	36	29.5	11	293	26
CCL (KFT)	9.5	4.5	13.5	13	295	38
Tc (oF)	87	71	92	15	305	40
Tmax (oF) (forecast)	87	88	87	18	295	42
700 mb T-Td	5	2	11	26	295	40
LOW-LVL MOISTR (g/kg)	8.1	10	5.5	FLOOD	DIST I	DIST II
PCBL. WATER (in.)	.91	1.06	.60	(in.)		

GREAT PLAINS CLOUD MODEL

NATURAL / MODIFIED	BIS CLOUD TOP kft	BIS CLOUD TOP oC	BIS MAX UPDFT m/s	GGW CLOUD TOP kft	GGW CLOUD TOP oC	GGW MAX UPDFT m/s	RAP CLOUD TOP kft	RAP CLOUD TOP oC	RAP MAX UPDFT m/s
1.0 km									
2.0 km									
3.0 km									

WORD FORECAST: Cu developing this aftn with R developing in No Dak later & continuing thru the evening. Significant 500mb SW moving thru. Moisture is good, as is the instability.

SFN 11811

DATE/TIME: 6-29-87

SOUNDING PARAMETERS	1200Z ANALYSIS			0000Z FORECAST		
	BIS	GGW	RAP	BIS	GGW	RAP
500 mb TEMP (oC)	-18	-18	-12			
TOTAL TOTALS	48	50	42			
K INDEX	29	30	25			
SWEAT INDEX	—	101	—			
LIFTED INDEX	+1	-2	+3	ANALYZED WINDS		
WET BULB 0 (KFT)				KFT	DD	FF kts
0 oC HEIGHT (KFT)	10	10	11.5	3	310	25
-5 oC HEIGHT (KFT)	11.5	13	14.5	5	320	18
-10 oC HEIGHT (KFT)	13.5	14.5	16.5	7	320	12
TROP HEIGHT (KFT)	29.5	27.5	36.5	9	340	15
EXPCTD HT. OF FREE CONVECTION (KFT)	10.0	27.5	12.5	11	350	15
CCL (KFT)	4.5	6.0	9.0	13	330	15
Tc (oF)	61	64	69	15	330	15
Tmax (oF) (forecast)	Lo 70's			19	310	15
700 mb T-Td	1	2	4	23	330	15
LOW-LVL MOISTR (g/kg)	7.6	8.0	7.4	FLOOD	DIST I	DIST II
PCBL. WATER (in.)	.78	.80	.58	(in.)		

GREAT PLAINS CLOUD MODEL

NATURAL / MODIFIED	BIS CLOUD TOP kft	BIS CLOUD TOP oC	BIS MAX UPDFT m/s	GGW CLOUD TOP kft	GGW CLOUD TOP oC	GGW MAX UPDFT m/s	RAP CLOUD TOP kft	RAP CLOUD TOP oC	RAP MAX UPDFT m/s
1.0 km									
2.0 km									
3.0 km									

WORD FORECAST: Lots of sc/cu - scattered RW- through early aftn. Clearing late aftn.

SFN 11811

DATE/T

7-4-87

SOUNDING PARAMETERS	1200Z ANALYSIS BIS	GGW	RAP	0000Z FORECAST BIS	GGW	RAP
500 mb TEMP (oC)	-9	-11	-12			
TOTAL TOTALS	47	47	49			
K INDEX	36	27	29			
SWEAT INDEX	122	60	27			
LIFTED INDEX	-1	-2	-2	ANALYZED WINDS		
WET BULB 0 (KFT)				KFT	DD	FF kts
0 oC HEIGHT (KFT)	13.5	12.5	13.5			
-5 oC HEIGHT (KFT)	16	15.5	16			
-10 oC HEIGHT (KFT)	19	18	17.5			
TROP HEIGHT (KFT)	38	38	34			
EXPCTD HT. OF FREE CONVECTION (KFT)	39	34	34			
CCL (KFT)	9	10	12			
Tc (oF)	86	85	85			
Tmax (oF) (forecast)						
700 mb T-Td	2	9	8			
LOW-LVL MOISTR (g/kg)	11	8.9	8.2	FLOOD	DIST I	DIST II
PCBL. WATER (in.)	1.18	.90	.86	(in.)		

GREAT PLAINS CLOUD MODEL

NATURAL / MODIFIED	BIS CLOUD TOP kft	BIS CLOUD TOP oC	BIS MAX UPDFT m/s	GGW CLOUD TOP kft	GGW CLOUD TOP oC	GGW MAX UPDFT m/s	RAP CLOUD TOP kft	RAP CLOUD TOP oC	RAP MAX UPDFT m/s
1.0 km									
2.0 km									
3.0 km									

WORD FORECAST: WARM FRONT IN E MT, COLD FRONT S. ALBERTA. UNSTABLE, WEAK SHORT WAVE.
WIDELY SCTD RW/TSTM AFTN
in General CU/SC/AC cover

SFN 11811

APPENDIX C: TRANSCRIPTIONS OF T-28 PILOT'S VOICE NOTES

IN FLIGHT CALIBRATION SEED 9, 10, 11

DATE	FLT NO.	T.O.	LDG.	FLT. TIME	DATA TIME	# PENETRATIONS
06/09/87	471	1630	1750	1.3		Test Flight

TIME	POSITION	ALT.	HDG.	REMARKS
1723:19				In-trail with (Duke) Seed 11 #1, Seed 10 (T-28) #2, and Seed 9 (Citation) #3.
1726:36				SF_6 was released by Seed 11 and ground data indicated that T-28 had positive detection.

DATE	FLT NO.	T.O.	LDG.	FLT. TIME	DATA TIME	# PENETRATIONS
06/13/87	472	1515	1700	1.8		SF_6 Test Flight

TIME	POSITION	ALT.	HDG.	REMARKS
1513:54	Dickinson			Injection on ground
1536:19	270/33.7	10000	270	+10? injection 1536
1555:15 →	270/36	15000	090	Injection { may be ±0°
1557:14	270/15	15000	090	Injection { same one
1600:00	270/15	20000	280	Injection
				This flight also for checks of radio receiver range at 75NM west, at 20000 feet and at 8000 feet altitude.

DATE	FLT NO.	T.O.	LDG.	FLT. TIME	DATA TIME	# PENETRATIONS
06/14/87	473	1015	1145	1.5		Test SF_6

TIME	POSITION	ALT.	HDG.	REMARKS
1021:10				Injection of gas on ground.
1048:54 1051:07	270/31.4	20000	270°	-15° Injection of gas
1055:20 1058:02	?	17000	100	-8° Injection of gas
1100:58 1104:00	?	15000	270°	-4° Injection of gas
1108:06 1110:46	?	10000	100°	Injection of gas

DATE	FLT NO.	T.O.	LDG.	FLT. TIME	DATA TIME	# PENETRATIONS
06/16/87	474	1358	1555	2.1		4

TIME	POSITION	ALT.	HDG.	REMARKS
1357:09	182/3.7			On gnd VOR check
1445:00		16000	010	150 IAS, 33", 2300 RPM, -7° Mod turb, moisture, icing ↑ 800', graupel, sampler on
1451 1454:06		16000	260	150 IAS, mod turb same as previous run
1500?	275/27?	16000	?	Tape unreadable
1500:51		16000	?	Tape unreadable
1537				Remarks were VOR/DME checks see separate sheet

* = VOR/DME CHECKPOINTS

DATE	FLT NO.	T.O.	LDG.	FLT. TIME	DATA TIME	# PENETRATIONS
06/16/87	474	1355	1550	1.9		4

TIME	POSITION	ALT.	HDG.	REMARKS
*1357:09	Before T/O			182°/ 3.7 NM DIK VOR
1445	?	160	090	150 A/S 33 MAP 2300 RPM On SW edge of TSTM Mod Turb, SEV turb, graupel ↑ 1500 FPM, -7°C, 1/2" rime ice
1451	?	160	265	150 AS -7°C MOD-SV Turb On Sw edge of TSTM Graupel 1" Rime ice Same as previous
?	275/8.7	160	120	150 AS Mod turb Smaller feeder
1506:57	275/5.0	160	300	150 AS Mod turb
*1536:43	180/5.1			VOR/DME Check
*1537:56	150/5.4			"
*1538:43	120/5.6			"
*1539:47	090/4.3			"
*1540:32	060/4.3			"
*1541:30	030/4.5			"
*1542:10	360/3.9			"
*1542:56	330/4.3			"
*1543:52	300/4.9			"
*1544:56	270/5.0			"
*1545:42	240/5.2			"

DATE	FLT NO.	T.O.	LDG.	FLT. TIME	DATA TIME	# PENETRATIONS
06/18/87	475	1610	1800	1.8		9

TIME	POSITION	ALT.	HDG.	REMARKS
1658 1701	320/27	16000	110	-8°, 32", 2300 lt turb Moisture
1706 1708:45	325/26	16000	325	Heavy moisture -8°C ice
1714 1716:16	340/31.8 318/26.6	16000	150	150 IAS Good moisture
1719:40	350/24.5 348/30.8	16000	350 330	Lt turb, moisture (good)
1724:12 1726	343/32 350/28	16000	150	Lt turb, good moisture
1729:32 1730:53	352/28	16000	330	Lt turb, good moisture
1733:16	345/33 350/28	16000	145	Same as above
1735:20	350/29 (approx.)	16000	340	Cloud decreasing light moisture missed main part due to cloud wash out.
1741:03	345/33 350/28	16000	150	Cloud washing out, very lt

SF_6 TEST AT LOW ALTITUDE

DATE	FLT NO.	T.O.	LDG.	FLT. TIME	DATA TIME	# PENETRATIONS
06/19/87	476	1410	1550	1.7		N/A

TIME	POSITION	ALT.	HDG.	REMARKS
				SF_6 released at ground level at the Dik VOR. T-28 flew the 5 DME Arc between the 250° and 350° radials at 1000' AGL, 1500 AGL, 2000' AGL, 2500'AGL and 3000' AGL. SF_6 was detected according to "CHILL" on some of the passes.

TOWER FLY-BY (BOWMAN, ND)

DATE	FLT NO.	T.O.	LDG.	FLT. TIME	DATA TIME	# PENETRATIONS
06/22/87	477	0550	0750	2.0		15

TIME	POSITION	ALT.	HDG.	REMARKS	
0653:47	Bowman Apt	35'	110°	160 IAS	
1656:48	"	"	"	"	
0700:20	"	"	"	"	
0704:26	"	"	"	"	
0708:20	"	"	"	"	
0712:42	Bowman Apt	35'	110°	120 IAS	
0716:34	"	"	"	"	
0720:31	"	"	"	"	7:19:35
0725:31	"	"	"	"	7:23:25
0728:10	"	"	"	"	7:27:55
0732:17	Bowman Apt	35'	110°	140 IAS	7:31:45
0735:56	"	"	"	"	7:35:01
0739:48	"	"	"	"	7:38:41
0743:40					
0744:00	"	"	"	"	7:42:48
0747:54	"	"	"	"	7:47:05

LANDSAT

DATE	FLT NO.	T.O.	LDG.	FLT. TIME	DATA TIME	# PENETRATIONS
06/22/87	478	1045	1120	1.0		2

TIME	POSITION	ALT.	HDG.	REMARKS
1100:53	DIK 275°/40.3	18100	345° ?	-15°C 200-300' below cloud tops, light ice particles
1109	DIK 293°/22.5	19000	100° ?	-16° very light clouds

SF_6 ENCOUNTERED ON THIS MISSION

DATE	FLT NO.	T.O.	LDG.	FLT. TIME	DATA TIME	# PENETRATIONS
06/28/87	479	1550	1730	1.7		10

TIME	POSITION	ALT.	HDG.	REMARKS
? in 1621:32 Out	260/50	10000	?	Lt turb, moisture
In 1624:07 Out 1625:08	265/38	10000	130	±0°, lt updraft ↑ 200 fpm moisture
1626:45 1628:44	?	11000	App. 270	-4°, 500' fpm ↑, moisture ice building
1630:05	?	12000	100	-6° turbulence, moisture ice combined clear and rime 700 fpm ↑, ice on windscreen and leading edges
1635	255/35	12000	255	-6° moisture, ice building continues, 500 fpm updraft, then 700 fpm ↑
1640:55 1642:27	? 255/37	13000	065	-6°, moisture, heavier ice 500 fpm, updraft ↑
1645 1647.53	250/35 252/39.8	14000	255 270	updraft 500 fpm, moisture, ice on windscreen -8°
1650.20 1652:02	252/39	14000	100	Updraft 500 fpm, ice, moisture
1654 1656:39	250/32.9 245/37	14000	250	Turb, moisture, ice
1658:01	245/36.5	14000	080	ice, moisture
				Ice buildup reached 1" + descended to 9,000 to burn ice off - then too late (for fuel) to climb back.

DATE	FLT NO.	T.O.	LDG.	FLT. TIME	DATA TIME	# PENETRATIONS
06/29/87	480	1355	1550	1.9		8

TIME	POSITION	ALT.	HDG.	REMARKS
1502:16	?	8000	180	Updraft (small) very light clouds
1505 1506:12	?	8000	035	Light clouds
		9000		Blank pass, equipment not on
1509:15 1510:20	135/36	9000	?	300' fpm updraft
1512 1512:42	?	10000	?	Cloud breaking up
1515:52	215/30	10000	?	Light cloud
1519:37 1520:26	?	9000	115 /?	Light cloud
1522:16	?	10000	295	Light cloud
1525:44 1527:06	210/26	10000	115	Light cloud
				Very poor quality tape on this mission, information limited.

DATE	FLT NO.	T.O.	LDG.	FLT. TIME	DATA TIME	# PENETRATIONS
07/04/87	481	1430	1630	2.0		8

TIME	POSITION	ALT.	HDG.	REMARKS
1514:09 1515:16	240/47	19000	042	-16°, turb updraft 500↑ - 700 fpm moisture, ice on windshield had appearance that may be hail or near hail stage. Hail catcher on
1520:20 1521:31	237/38.3 237/43	19000	235	Turbulence, updraft 500 fpm Good moisture Hail catcher on
1525:02 1526:27	237/44.5 237/38	19000	055	Turbulence, updraft decreasing Still good moisture
1529:14 1531:15	235/37	19000	240	Cloud intensified on west/SW side
1533:29 1536:37	235/43	19000	050	Turbulence, 300-500 ↑ updraft Moisture
1540:03 1541:42	235/38	19000	270	Same as above
1543:46 1545:44	?	19000	050	Moisture, turbulence
End? 1613:48	270/35	13000	100	Updraft, downdraft, moisture -4°C Made parallel track with SF_6 seeder then low on fuel RTB