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ANNUAL PROGRESS REPORT ON ARMORED T-28 AIRCRAFT FACILITY COOPERATIVE AGREEMENT (ATM-9104474)

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ABSTRACT

This is the annual progress report required under the terms of Cooperative Agreement No. ATM-9104474 between the National Science Foundation (NSF) and the South Dakota School of Mines and Technology (SDSMT). This agreement provides base support for the operation of the SDSMT armored T-28 meteorological research aircraft as a national facility for investigations into cloud, thunderstorm, and hailstorm processes. Since the beginning of this agreement in 1991, field deployments each summer were funded through other sources, including the NSF Lower Atmospheric Research Facilities Deployment Pool. The period covered by this report is 16 February 1993 through 15 February 1994. During this period, the T-28 participated in the North Dakota Tracer Experiment, an investigation of transport, dispersion, ice initiation, and hail development in High Plains convective clouds. In addition, research results from prior projects were described in research papers accepted by refereed journals and presented at national conferences; many included facility personnel as co-authors. Additional development work in the area of instrumentation, aircraft systems, and data analysis and interpretation was carried out.

1. INTRODUCTION

This annual progress report on T-28 research aircraft facility activities under Cooperative Agreement No. ATM-9104474 covers the period 16 February 1993 through 15 February 1994. The major project support activity during this period was a 6-week deployment to Bismarck, North Dakota, to participate in the North Dakota Tracer Experiment (NDTE) during June and July 1993. The focus of this experiment was to trace the air motions and development of precipitation in High Plains cumulus clouds of various sizes in a variety of weather regimes. In preparation for this deployment, a sulfur hexafluoride (SF_6) analyzer was installed on the aircraft and several upgrades to the avionics and aircraft instrumentation were completed. This allowed the T-28 to be used as one of two aircraft participating in the NDTE which effectively traced the transport and dispersion of SF_6 released by a third aircraft, as this gas was carried within cumulus cloud circulations.

Instrumentation developments included further enhancement of an imaging capability for the South Dakota School of Mines and Technology (SDSM&T) hail spectrometer, development of a spray rig to test the aircraft liquid-water probes, further developments in the processing of cloud droplet spectral data, addition of a fifth field mill to the suite of electric field measuring equipment on the aircraft, and special tests with two discharge probes to improve our understanding of aircraft charging. Facility personnel continued to assist in the analysis and publication of results from past T-28 deployments going back to 1989.

Further details of these activities are presented in subsequent sections.

2. PROGRESS THROUGH THE YEAR

2.1 Project Support

The armored T-28 aircraft was deployed to Bismarck for the six-week period 21 June through 30 July 1993 in support of the following NDTE objectives:

- Mapping of transport, dispersion, and entrainment in cumulus clouds using tracers.
- Study of ice initiation and precipitation development in feeder/daughter cells associated with thunderstorms.
- Study of the relationship between cloud electrification, lightning activity, and precipitation development.

The deployment, requested by a group of NSF-funded SDSM&T researchers on behalf of the NDTE scientific community, was funded from the North Dakota portion of the National Oceanic and Atmospheric Administration (NOAA) Federal/State Cooperative Program in Atmospheric Modification Research (AMP). The T-28 is normally well-equipped for productive data acquisition in support of the latter two of the above objectives. Installation and maintenance of an SF_6 analyzer by North American Weather Consultants (NAWC) during the NDTE allowed the T-28 to be used in tracer studies related to transport, dispersion, and entrainment processes, the first objective listed above. The analyzer was modified by NAWC for the NDTE to improve its performance above 5 km MSL in light of problems encountered when similar equipment was mounted on the T-28 in 1989.

Table 1 summarizes T-28 flight activity during the NDTE. The aircraft was flown to Salt Lake City on 23 May for installation of the SF_6 analyzer. After return to Rapid City for a test flight, it was then ferried to Bismarck for some avionics work in preparation for the field season. The cool wet summer of 1993 in the High Plains provided large numbers of suitable clouds for study. The T-28 performed 14 research flights along with a tower fly-by and one test flight during the period of the NDTE. More than 150 cloud penetrations were logged during the course of these flights. The total of 42 hours flown represents a 50% increase, and the 14 research flights a 100% increase, compared to the same totals for the six-week North Dakota Thunderstorm Project carried out in the dry summer of 1989.

The primary role of the T-28 in the NDTE was to penetrate middle and upper regions of convective clouds following dispersal of SF_6, 3 cm radar

TABLE 1

T-28 Flights - Summer 1993

Date (1993)	Flight No.	Time (h)	Purpose
20 May	593	1.3	Local test
23 May	594	2.5	Ferry to RKS (fuel stop)
23 May	595	0.9	Ferry to SLC
30 May	596	1.8	Ferry to CPR (fuel stop)
30 May	597	1.1	Ferry to RAP
14 June	598	1.4	Local test & pilot checkout
14 June	599	1.3	Ferry to BIS
22 June	600	1.7	Research
26 June	601	2.5	Test
29 June	602	1.3	Research
30 June	603	1.9	Research
1 July	604	1.7	Research
3 July	605	1.9	Research
6 July	606	2.1	Research
8 July	607	1.9	Research
9 July	608	1.8	Research
15 July	609	1.6	Research
18 July	610	2.8	Research
22 July	611	1.6	Research
23 July	612	1.9	Research
25 July	613	2.0	Research
27 July	614	2.2	Research
29 July	615	1.2	Test (tower fly-bys)
30 July	616	1.3	Ferry to RAP
Total		41.7	

chaff (to be traced by the NOAA-C circularly polarized radar), and/or fluorescent beads (intended to act as artificial precipitation embryos), in the lower to middle regions of the clouds by another specially-equipped project aircraft. Equipment on the T-28 (see Table 2) was capable of detecting the SF_6 tracer gas, characterizing cloud microphysics, and capturing precipitation particles for later laboratory analysis. The T-28 was involved in 19 tracer experiments during the summer, and encountered the SF_6 tracer on almost half of them. The cases with no SF_6 detections provide information about where the tracer was not, and the chaff observations from NOAA-C can help to fill in the picture of tracer transport in those clouds. The revamped SF_6 analyzer worked fairly well, although the new pilot adjustment capability was not fully successful in suppressing the oscillations that tend to occur at high altitudes.

From an operational standpoint, the reliable operation of the air-to-ground telemetry system was a highlight of the project. Previous difficulties with this system had been resolved as a result of the Software/Hardware Test deployment to Colorado in 1992. Global Positioning System (GPS) aircraft track data transmitted over the telemetry link to the NDTE Operations Center were ingested into the University of North Dakota C-band weather radar data system for overlay on the PPI displays. This provided reliable information to the Aircraft Coordinator for directing the T-28 cloud penetrations.

On a sour note, the difficulties with P-static in the air-to-ground VHF radio communication continued to hamper the coordination of the T-28 activities. Difficulties with obtaining a functioning replacement attitude indicator (we tried three different units) grounded the aircraft for two days early in the project, but those days were characterized by mostly embedded convection that was not well suited to the T-28 mission. One takeoff had to be aborted because of a prop governor failure. During a penetration on 23 July, the aircraft popped several rivets on the skin of the upper wing, but that was quickly repaired.

A detailed summary of T-28 activities during its deployment to the NDTE is provided in Detwiler *et al.* (1994c). Appendix A provides a copy of a letter from Mr. Bruce Boe, NDTE project organizer, concerning the T-28 support of the field project. Data analysis is in its early stages at this time, but it is readily apparent that many individual well-executed cumulus cloud experiments from the NDTE will provide new insights into the workings of High Plains cumulus clouds.

TABLE 2

Basic T-28 Instrumentation

VARIABLE	INSTRUMENT	RANGE	ACCURACY	RESOLUTION (as recorded)	NOTES
STATIC PRESSURE	ROSEMOUNT 1301-A-4B	0-15 psi (0-103 kPa)	±0.015 psi (±0.1kPa)	0.0002 psi (0.002 kPa)	• Bench calibration, 6/93
	ROSEMOUNT 1301-A-4B	5-15 psi (35-103 kPa)	±0.015 psi (±0.1kPa)	0.0002 psi (0.002 kPa)	• Bench calibration, 6/93
TOTAL TEMPERATURE	ROSEMOUNT 102AU2AP	-30 - +30°C	±0.5°C	0.001°C	• Platinum wire • ~2 s time constant
	NCAR REVERSE FLOW	-30 - +30°C	±0.5°C	0.001°C	• Diode • Several seconds time constant • Bench calibration, 6/93 • Recovery factor adjusted, 6/93
CLOUD WATER AND CLOUD DROPLETS	JOHNSON-WILLIAMS LIQUID WATER CONCENTRATION	0 - 6 g/m^3	±20%	0.0001 g/m^3	• Accurate if all droplets have d <30 μm
	PARTICLE MEASURING SYSTEMS, INC. FORWARD SCATTERING SPECTROMETER PROBE	Size ~1 < 57 μm Concentration 0 - ~2000 droplets/ cm^3	±1 size channel in size and ±1% in concentration 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 concentration ~ ±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 m3/km
	PARTICLE MEASURING SYSTEMS, INC. 2D Cloud Probe	Size 25 - 800 μm	±25 μm	25 μm	• Computed ice and water concentration can vary ±50% with processing technique • Sampling rate: 0.05 m^3/km; DAS can accept ~250 particles/s (2500/km)
	HAIL SPECTROMETER	Size 4.5 mm - 4.5 cm Concentration 0 - 100/m^3	±1 size class	1 size class	• 14 size classes • Sampling rate 100 m^3/km • Alternates with particle camera
	NCAR PARTICLE SAMPLER				• A batch sampler, primarily for hailstones • Sampling rate 2.6 m^3/km

TABLE 2 (continued)

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 SSA09-D0101-1 VERTICALLY STABILIZED ACCELEROMETER	± 2 g's pitch -50° to +50° roll -50° to +50°	0.004 g 0.2° 0.2°	0.00006 g 0.002° 0.002°	
	ROSEMOUNT 1301-D-1B DYNAMIC PRESSURE	-3 to +3 psi (-20 to +20 kPa)	±0.1%	0.0001 psi (0.0006 kPa)	• Indicated airspeed • Bench calibration, 6/93
	ROSEMOUNT 1221-F-2A DYNAMIC PRESSURE	-2.5 to +2.5 psi (-18 to +18 kPa)	±0.1%	0.0001 psi (0.0006 kPa)	• Indicated airspeed • Bench calibration, 6/93
	GIANNINI 45218YE MANIFOLD PRESSURE	0 to 50 in Hg	±2%	0.008 Hg (0.03 kPa)	• Used in one vertical velocity calculation • Bench calibration, 3/93
	BALL ENGINEERING 101A VARIOMETER	-6000 to +6000 ft/min (-30 to +30 m/s)	±200 ft/min (±1 m/s)	0.2 ft/min (0.001 m/s)	
AIRCRAFT LOCATION	NARCO NAV-122 VOR	0 - 360°	±2°	0.005°	
	CESSNA 400 DME	0 - 100 nmi (0 - 185 km)	0.1 nmi (185 m)	0.002 nmi (3 m)	• Maximum 2 s to lock on and acquire range
	TRIMBLE TNL2000 GPS	(global)	30 m	18 m	• LORAN unit not available in 1991
ELECTRIC FIELD	NMIMT Model E-100 DC Electric Field Meter	top/bot ±650 wings ±3200 5th ±340 } $\frac{kV}{m}$		(coarse resolution) 0.01 $\frac{kV}{m}$	

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.

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2.2 Instrumentation Development

Further development of the imaging capabilities of the hail spectrometer was accomplished during the spring and summer of 1993, with the collaboration of Science Engineering Associates (supplier of the T-28 data acquisition system). Last year, imaging capabilities were demonstrated in the lab. This year brought the first successful images obtained during flight since 1986, when limited success was obtained using the previous T-28 data system. An example of some of the images obtained is shown in Fig. 1. The main limitation on performance of the hail spectrometer as of this time appears to be water accumulating on the probe pylons and streaming across the optical path, near one end or the other, leading to large numbers of spurious images. A new deflector system is being designed and will be tested during field deployments currently being planned for the summer of 1994.

Facility staff developed a spray rig that provided a reproducible water spray for testing the T-28's Johnson-Williams cloud water meter and Particle Measuring Systems, Inc., (PMS) Forward Scattering Spectrometer Probe (FSSP). Figure 2 shows an example of the response of the two J-W probe heads to the same water spray. Although the system is not yet suitable for quantitative calibration, it can be used to test for relative changes in instrument response during a field deployment and thus provide an alert that an instrument needs attention if its response changes.

Further work was done with the FSSP data reduction routines. Corrections suggested in the literature have been applied and lead to higher estimates of integrated cloud water concentrations. An example

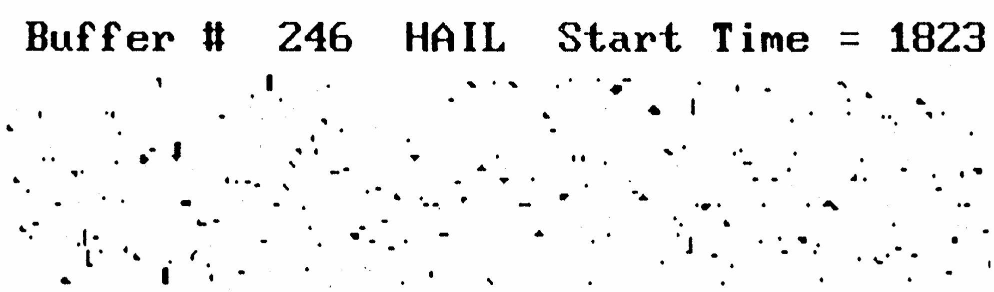

Fig. 1: Example of images obtained from the T-28 hail spectrometer during the NDTE. Vertical dimension of sampling aperture is 11.5 cm.

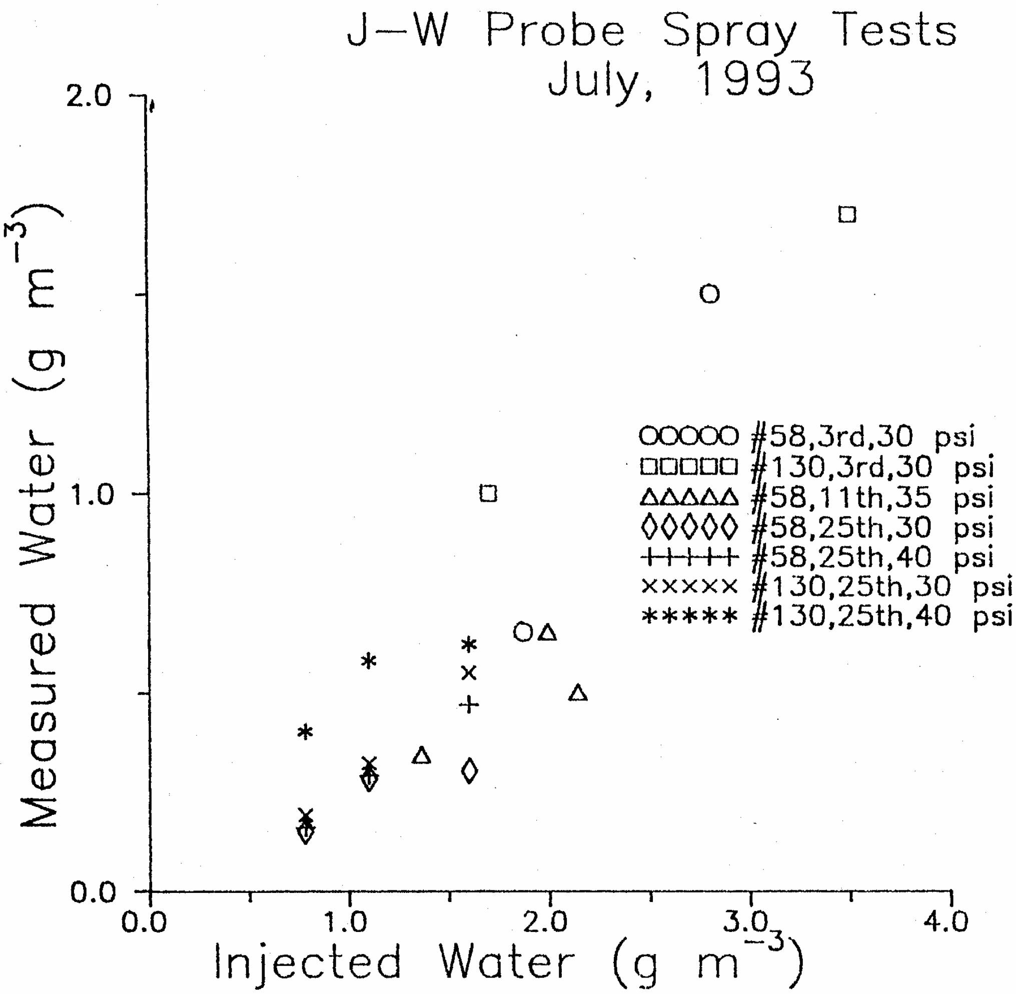

Fig. 2: Results of spray rig tests of the J-W cloud water meter. Results are shown for two heads (#58 and #130) on different days (July 3, 11, and 25, 1993) with different air pressures applied to the spray nozzle.

is shown in Fig. 3. Further analysis is under way in an attempt to produce the best possible data reduction scheme.

The telemetry system has been modified so that selected event codes are transmitted outside the normal data stream; this streamlines the real-time monitoring of instrument systems by staff on the ground. High-precision GPS information, including geometric altitude, is now being transferred into the telemetered data stream. (These developments occurred after the NDTE.)

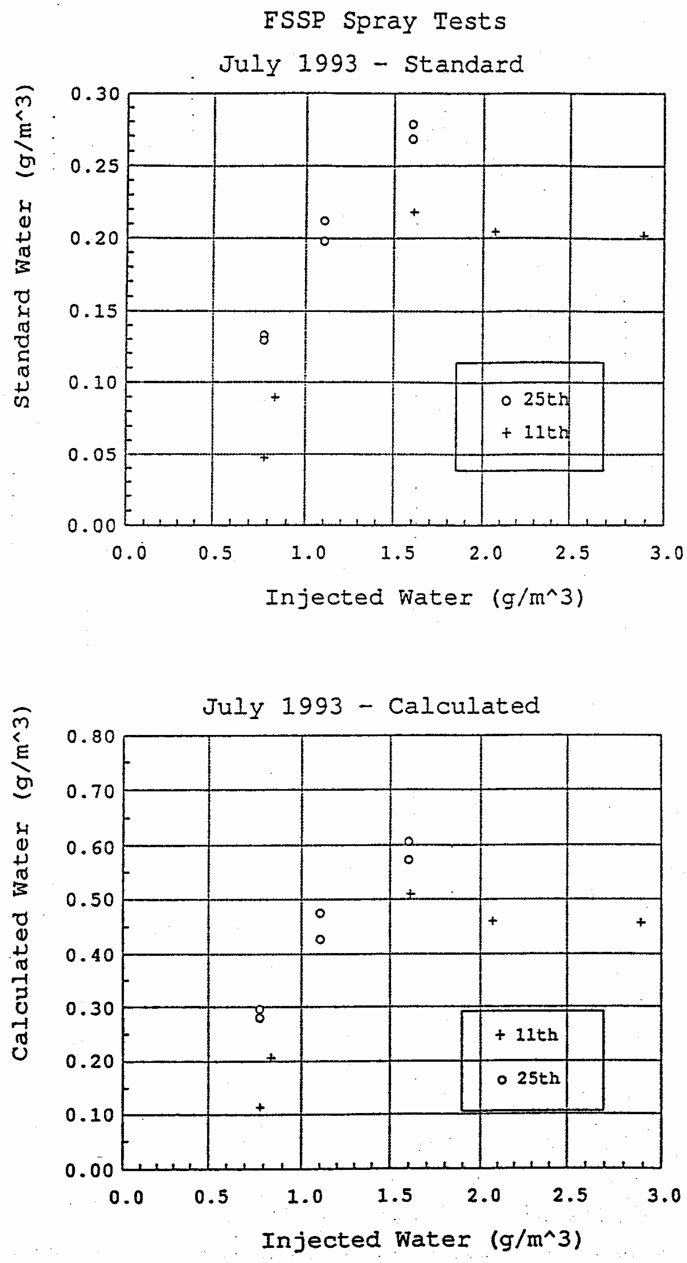

Fig. 3: Data from FSSP spray rig tests on two different days are shown. Integrated water content is shown as estimated using the standard T-28 FSSP data reduction algorithm and also as estimated using the new algorithm, based on recently-published analyses of FSSP operation (labelled as "calculated" in the figure); both based on the same raw FSSP data. Note the change in ordinate scale between the top and bottom panel. The "calculated" (new algorithm) values are roughly twice the "standard" values for the same set of FSSP channel counts obtained at a particular water spray rate.

A fifth electric field mill was added to the field mill suite carried by the T-28. We still need to use two borrowed field mills for the complete installation, but the 5-mill system enhances the electric field measurement capability. The 4-mill suite carried by the T-28 since 1989 is adequate for measurement of the vertical and transverse components of the ambient electric field; however, ambiguous results are obtained for the along-fuselage field component in situations where the aircraft acquires significant charge. The fifth mill is intended to help reduce some of these ambiguities. Analysis of data obtained with the 5-mill suite during the NDTE is in progress and final results are anticipated in the next facility year.

Ms. K. L. Giori, of SRI International, assisted facility staff with interpretation of data from the field mill suite. In addition, she provided two instrumented discharge probes that were installed on the T-28 during the NDTE, one on the right wing and the other on the tail. Measured discharges from these probes are being used to provide additional information about aircraft charging and polarization characteristics. This will be helpful in further refining electric field estimates from the 5-mill suite.

In addition to the above-described development work, routine calibrations of the research instrumentation pressure and temperature transducers on the T-28 were completed in the spring of 1993. The temperature transducers were further calibrated during the NDTE using a newly-fabricated under-wing temperature chamber. The FSSP was calibrated with glass beads of known size and its optical characteristics determined. The PMS OAP 2D-C cloud-particle probe optics were calibrated with a Droplet Measurement Technologies (DMT) spinning disk device.

The NCAR Research Aviation Facility loaned a 2D-C probe for use during much of the project. We had been experiencing electronic problems with the T-28 probe, and the NCAR unit was used as a source for substitute circuit cards that helped greatly in providing quality image data.

Deicing systems in all microphysical probes were checked and refurbished as necessary. Open circuits in the FSSP and 2D-C probe deicing units were repaired.

To upgrade our data analysis capabilities in the field, a new 486-category Personal Computer with appropriate peripherals was purchased with local funds in time for use in the NDTE field project.

Laboratory work in collaboration with M. Gibson, an M.S. degree candidate in the SDSM&T Electrical Engineering Department, continued with the M-Disk device. This is a spinning-disk device suitable for measuring total water concentration in cloudy air. A prototype mechanical device has been demonstrated, and current work focuses on the feedback-control circuit. This work follows the path suggested by a theoretical analysis of a spinning disk in two-phase flow performed by H. Norment of Atmospheric Science Associates.

2.3 Data Analysis

Facility staff continued to lead in analyses of data from several previous T-28 field deployments as well as to assist other researchers in additional studies. In the summer of 1993, T. Walsh, now a PhD candidate in the Electrical Engineering Department at The Pennsylvania State University, completed his master's thesis (Walsh, 1993). It concerned an analysis of multi-parameter radar data and T-28 observations within a hailstorm investigated on 5 June 1991 during the Cooperative Oklahoma Profiler Studies (COPS-91) deployment in Norman, Oklahoma. He was guided in his research by Prof. K. Aydin of Penn State and received assistance from T-28 facility staff. This analysis was sponsored by NSF.

At SDSM&T in February 1994, R. Ramachandran successfully defended his master's thesis describing research on electrification in several Florida thunderstorms during the 1991 Convection and Precipitation/ Electrification (CaPE) project (Ramachandran, 1994). He was supervised by facility scientist A. G. Detwiler, with assistance from V. N. Bringi at Colorado State University (CSU). His thesis focuses on two storms observed on 29 July 1991, with cursory attention being given to storms on 28 July, 31 July, and 13 August 1991. This analysis was sponsored by NSF.

Review comments on two journal manuscripts describing observations from the 1989 North Dakota Thunderstorm Project (NDTP) were received. The manuscripts were revised in response to those comments, returned to the journal editors, and subsequently accepted for publication in Atmospheric Research (one has already appeared; Detwiler *et al.*, 1994a). Additional data from another NDTP day (10 July 1989) were investigated in greater detail and the results were reported at the 26th International Conference on Radar Meteorology (Musil *et al.*, 1993). The work was partially sponsored by NSF under the facility agreement and a separate NSF grant.

W-Y. Chang, another M.S. candidate at SDSM&T, is nearing completion of his analysis of precipitation development in a 17 July 1989 NDTP squall line penetrated several times by the T-28. He is being supervised by Prof. M. Hjelmfelt and facility scientist Detwiler. This analysis is being sponsored by NOAA through the NDARB.

A third SDSM&T M.S. candidate, Jeffrey French, is completing his study of electrification of the second of two Florida thunderstorms repeatedly penetrated by the T-28 on 9 August 1991 during CaPE. Prof. J. Helsdon is guiding this research. This study is being sponsored by NSF.

A fourth SDSM&T M.S. candidate, Mark Bloomer, is beginning his research on evolution of feeder cells, and transport, dispersion, and entrainment in NDTE thunderstorms. He is working under the direction of Professors Hjelmfelt, P. L. Smith, and Detwiler on this NSF-sponsored study.

A fifth SDSM&T M.S. candidate, Yong Zhang, is being assisted by facility staff in his analysis of radar and T-28 data from a hailstorm encountered on 24 June 1992 during the RAPS-92 deployment to Greeley, Colorado. His prime focus will be a comparison between model simulations and observations within and around this storm, under the guidance of Prof. H. D. Orville. This work is sponsored by NSF. Facility staff have collaborated with E. A. Brandes of NCAR and V. N. Bringi at CSU in the analysis and interpretation of T-28 data from this 24 June 1992 storm, and have received guidance from them concerning Mr. Zhang's work.

Facility staff have also been collaborating with V. N. Bringi on detailed analyses of two storms that occurred on August 9, 1991, during CaPE. Emphasis has been placed on the relationship between the T-28 microphysics observations and multiparameter radar observations from the CP-2 system (Bringi *et al.*, 1993a,b). The facility staff has also been examining some of the data from other CaPE aircraft to obtain a more complete picture of the microphysical evolution of this storm system. Additional correspondence and data exchanges concerning these cases have been undertaken with Ian Brooks and C. P. R. Saunders at the University of Manchester Institute of Science and Technology in the United Kingdom; John Hallett at the Desert Research Institute; Bob Black at the National Hurricane Center; and Martin Murphy and Philip Krider at the University of Arizona. Two additional papers were presented in 1993 concerning these cases. One paper, presented at the 1993 Conference on Atmospheric Electricity, included discussion of these cases (Detwiler *et al.*, 1993c), and another presentation based on these cases was made as well at the Fall 1993 meeting of the American Geophysical Union (Detwiler *et al.*, 1993b).

Data analyses are being prepared to answer requests from Earle Williams concerning thunderstorm microphysics in Florida.

Facility staff have also collaborated with Larry Cornman and Gary Cunning of the NCAR Research Applications Program concerning turbulence calculations based on T-28 measurements. They have been adapting a technique based on accelerometer measurements developed for other aircraft to the T-28. We hope to compare their results to turbulence calculations based on dynamic pressure fluctuations, which has been the traditional approach with T-28 data since the first application of the fluctuation technique to the T-28 during the National Hail Research Experiment in the 1970's.

The facility scientist has been corresponding with Drs. George and Nikolay Miloshev of the Bulgarian Geophysical Institute concerning nucleation problems. The intent is to combine their theoretical insight with physical observations from *in situ* aircraft to better interpret cloud microphysics processes.

Other scientists continued their analyses of data collected by the T-28 in previous field projects, with several papers, in addition to those already mentioned, presented at the 26th International Conference on Radar Meteorology reflecting some of this work. Professor K. Aydin and associates presented an analysis of some of the data collected during the COPS-91 experiment in Oklahoma (Aydin *et al.*, 1993). Yuter and Houze (1993) also employed T-28 observations in their analysis of one CaPE case. Scientists analyzing the various observations from the RAPS-92 project are examining the T-28 data in the course of their investigations (e.g. Neilley *et al.*, 1993; Brandes *et al.*, 1993a; Bringi *et al.*, 1993c; Vivekanandan *et al.*, 1993).

Brandes *et al.* (1993b) presented a fairly detailed analysis of the 24 June 1992 case at the 5th Conference on Aviation Weather Systems last summer.

2.4 Aircraft Equipment and Maintenance

Aircraft maintenance and equipment developments within this period included:

Replacement of the artificial horizon, after difficulties with three successive refurbished 400 Hz units, with a commercial DC powered unit that is serviceable but has poorer resolution capabilities.

Upgrade of the Global Positioning System unit to provide GPS data at 1 s update intervals, along with higher precision LAT/LON and altitude data.

Repair and recalibration of the Humphrey accelerometer.

Replacement of the prop governor during the NDTE.

Minor repairs to various heater and deicing elements.

Repairs to wing panels, necessitated by rough flying conditions during the NDTE.

In addition, a variety of replacement parts have been ordered to replenish the stock of spares for the aircraft. A new aircraft pitot tube has been ordered to replace the one that has finally reached its limit with respect to damage by hailstone impacts in flight.

The State of Alaska has yet to surplus a T-28 that could be made available to SDSM&T, although some of its aircraft have been surplused to other non-profit entities. The Alaskan situation is being closely monitored, in hopes of obtaining an aircraft to bring to SDSM&T for spare parts.

2.5 Software Developments

Continued enhancements to existing software packages have been carried out. Further work on the FSSP data reduction routines continues, as described above. Ms. Giori's most recent work on retrieving ambient electric fields from aircraft field mill readings has been implemented. Some software is being slowly migrated to the UNIX environment so that it can be supplied to data users who work in that environment.

2.6 Data Exchanges and Information Requests

In addition to the collaborative exchanges listed above, the following activities took place within the reporting period:

- Assistance to Florida State University students working with T-28 data from CaPE.
- Loan of a foil reader to the NCAR RAP group analyzing T-28 data from RAPS-92.
- Discussion of possible use of the HVPS large-particle imaging probe developed by Paul Lawson of SPEC, Inc., on the T-28. Support costs and deicing power requirements are potential problems.

- Discussion with Michael Bradley of the Department of Energy concerning a possible T-28 deployment to the ARM site in Oklahoma in the spring of 1994.

- Discussions with Dusan Zrnic and Jerry Straka concerning a possible T-28 deployment to Norman, Oklahoma, during the VORTEX program planned for April-May 1994. A facility request resulted from these discussions.

- Discussions with William Woodley and George Bomar concerning a possible T-28 deployment to Big Spring, Texas, in August 1994, to support cloud modification studies funded by the NOAA Federal/State AMP. A facility request also resulted from these discussions.

An article about the North Dakota projects, highlighting the T-28, appeared in the April 1993 issue (Vol. 9, No. 4) of IFR magazine.

2.7 Educational Activities

In addition to the six graduate students mentioned in Section 2.3, undergraduate students A. Linden, M. Gibson, and J. Tomac have assisted in facility activities during the reporting period.

Facility staff briefed a contingent of broadcast journalists who visited the NDTE site on 12 July 1993, and a contingent of SDSM&T graduate students who paid a 2-day visit to the NDTE site on 13-14 July 1993. A static public display of the T-28 was staffed during the NDTE on 15 July 1993.

Facility staff scientists Kelley and Detwiler participated in SDSM&T's Visiting Scientist program, making several dozen presentations to elementary and secondary school groups concerning airborne meteorological studies and severe storm phenomena.

2.8 Travel

The following travel in support of facility activities was accomplished during the year:

Paul L. Smith to NSF offices in Washington, 31 March 1993.

Paul L. Smith to Boulder for OFAP/FAC meetings, 3-5 May 1993.

Richard F. Kelley to Boulder for PMS probe work, 16-20 May 1993.

Daniel P. Custis to Salt Lake City with T-28 for SF_6 analyzer installation, 23 and 30 May 1993.

Daniel P. Custis to Bismarck with T-28 for avionics work, 14 June 1993.

Richard F. Kelley to Bismarck for NDTE, 20 June through 31 July 1993.

Andrew G. Detwiler to St. Louis to present a paper at Atmospheric Electricity Conference, 4-8 October 1993.

Paul L. Smith to Boulder for OFAP/FAC meetings, 17-20 October 1993.

Daniel P. Custis to Atlantic City to visit FAA laboratories, 11 November 1993.

Andrew G. Detwiler to San Francisco, CA, to present paper at Fall AGU meeting, 8-10 December 1993.

Paul L. Smith to Nashville for FAC meeting, 26 January 1994.

3. FUTURE PLANS

A proposal is now pending for renewal of the Cooperative Agreement supporting the T-28 facility. The extent to which the following plans can be implemented depends upon the outcome of that proposal.

3.1 Field Projects to be Supported During the Coming Year

The T-28 will be participating in the VORTEX project in central and western Oklahoma during May 1994. Its role will be to provide *in situ* measurements in thunderstorm volumes being scanned by the multi-parameter Cimarron radar operated by the National Severe Storms Laboratory. Support for the deployment will come from the NSF Lower Atmospheric Research Facilities deployment pool.

A request is pending for the deployment of the T-28 to Greeley, Colorado, from mid-June through mid-July 1994, to support the RACES experiment. The T-28 would collaborate with the NCAR sailplane and CSU-CHILL multiparameter radar in studies of electrification in hail-bearing storms. Support for the deployment would also come from the NSF facilities deployment pool.

A third request is pending for deployment of the T-28 in 1994, this one to Big Spring, Texas, during August to support studies of microphysical evolution in seeded and natural cumulus clouds. Support would come from the NOAA Federal/State AMP, through the Texas component of the program.

3.2 Data Analysis

Data analysis from the 1989 deployments is slowly coming to completion. Work on data from CaPE and the NDTE will be a primary focus over the next year.

3.3 Facility Development Activities

Further effort to improve interpretation of data from the FSSP is under way, with the assistance of an undergraduate student. A report summarizing performance and analysis of data from the FSSP is in preparation. An upgrade to the data acquisition software will be procured to improve the hail spectrometer imaging system.

Further testing and analysis of the electric field measuring system will be pursued. A report summarizing current understanding of this system is now in preparation. A consultant will be engaged to help with the persistent P-static problems on the aircraft.

Quality control documentation and data summaries from the 1993 summer's deployment(s) will be prepared.

Efforts will continue to acquire a surplus T-28 from the State of Alaska as a source of spare hardware.

3.4 Future Field Projects

There are no firm requests for projects in future years at this time. It is possible that either or both of the potential mid-to-late summer 1994 deployments could slip to 1995 or later. There will be a second year of activity in the VORTEX program in 1995 that may warrant T-28 participation. The Illinois group under the Federal/State AMP program is also beginning to plan for a convective-cloud field project in 1995 (or perhaps later) that may require T-28 participation.

4. PERSONNEL

Charles A. Summers participated with gusto in the NDTE, splitting flight duties with the "regular" T-28 pilot, Dan Custis. Mr. Summers' schedule is very full for 1994, and it is not known at this time how much he may be able to participate in T-28 deployments.

Dennis Musil once again came out of retirement to serve as the aircraft coordinator for the NDTE. His responsibilities included not only directing the T-28 flights but also coordinating the activities of all three project aircraft.

Richard Kelley's participation in facility activities has diminished as he has taken on additional teaching duties in the SDSM&T Physics Department. However, he still leads facility efforts dedicated to calibration and maintenance of the optical probes and temperature sensors.

5. PUBLICATION ACTIVITY

Published in Refereed Journals

Detwiler, A. G., N. C. Knight and A. J. Heymsfield, 1993a: Magnitude of error factors in estimates of snow particle masses from images. *J. Appl. Meteor.,* **32**, 804-809.

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Detwiler, A. G., P. L. Smith, J. L. Stith and D. A. Burrows, 1994b: Observations of microphysical evolution in a High Plains thunderstorm anvil. *Atmos. Res.*, **31**, --.

Presented at conferences

Bringi, V. N., A. Detwiler, V. Chandrasekar, P. L. Smith, L. Liu, I. J. Caylor and D. Musil, 1993b: Multiparameter radar and aircraft study of the transition from early to mature storm during CaPE: The case of 9 August 1991. Preprints, *26th Intnl. Conf. Radar Meteor.,* Norman, OK, Amer. Meteor. Soc., 318-320.

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Ramachandran, R., and A. G. Detwiler, 1993: Study of electrification in thunderstorms using *in-situ* aircraft measurements. Presented at 78th Annual Meeting, South Dakota Academy of Science, Rapid City, SD, 16-17 April 1993.

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Detwiler, A., J. French, J. Helsdon, Jr., R. Ramachandran and K. Giori, 1993b: Airborne *in situ* electric field measurements in Florida thunderstorms. Presented at the Fall Meeting of the American Geophysical Union, 6-10 December, 1993, San Francisco, California.

The following referenced items are based in part on analysis of T-28 data by scientists from other institutions:

Aydin *et al.,* 1993.

Brandes *et al.,* 1993a.

Brandes *et al.,* 1993b.

Bringi *et al.,* 1993a.

Bringi *et al.,* 1993c.

Neilley *et al.,* 1993.

Vivekanandan *et al.,* 1993.

Yuter and Houze, 1993.

Walsh, 1993.

Other Items

Smith, P. L., J. L. Stith, A. Borho, R. F. Reinking and B. E. Martner, 1993: North Dakota Tracer Experiment investigates cloud transport processes. "*The Earth Observer,*" EOS Project Science Office, NASA Goddard Space Flight Center, Greenbelt, MD, 5:6, 34-36.

Ramachandran, R., 1994: Analysis of Florida Thunderstorms. Study of Electrification using In Situ Aircraft Measurements and Multiparameter Radar. Master of Science thesis, Department of Meteorology, South Dakota School of Mines and Technology, Rapid City, South Dakota. 96 pp.

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Detwiler, A., J. French, J. Helsdon, Jr., R. Ramachandran and K. Giori, 1993b: Airborne *in situ* electric field measurements in Florida thunderstorms. Presented at the Fall Meeting of the American Geophysical Union, 6-10 December, 1993, San Francisco, CA.

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APPENDIX A

NORTH DAKOTA

Atmospheric Resource Board

A DIVISION OF THE NORTH DAKOTA STATE WATER COMMISSION

900 EAST BOULEVARD • BISMARCK, NORTH DAKOTA 58505-0850 • (701) 224-2788 • FAX (701) 224-4749

DEC 13 1993

9 December 1993

Dr. Paul L. Smith, Director
Institute of Atmospheric Sciences
SD School of Mines & Technology
501 East St. Joseph Street
Rapid City, SD 57701-3995

RE: Performance of T-28 in the NDTE

Dear Paul:

I've intended to write this letter since shortly after the end of the field effort, but until now, other matters have diverted my attention.

In evaluating the performance of a research aircraft in the field, there are four things to consider. They are: the aircraft itself, the instrumentation, response time, and finally, the ability to get the aircraft where we needed it to be to collect the required data. I'll address each of these separately, though there is some overlap.

The Aircraft

Jon Leigh did his usual fine job, as the aircraft was operational for virtually the whole program. I recall only the problems with the attitude indicator and a few hours lost while boot glue cured. In contrast with the problems experienced by the Citation (pressurization problems, bad radios, flooded engines, etc.) the T-28 fared very well indeed.

The Instrumentation

Occasional glitches with the SF_6 system kept Dan Risch busy, but overall the detector worked fairly well. I recall also the failure of a small nylon gear in the hail collector which kept it out of action for a few days. Other than that, I can't recall any data collection problems. Andy, Gary, and Ken always stayed on top of things. The real-time data telemetry worked well, and the GPS positioning on the radar display proved very useful. Dennis seemed more comfortable

Dr. Paul L. Smith, cont'd
9 December 1993
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directing the T-28 from that display than he ever did with the NCAR displays during the NDTP. I would highly recommend that system to anyone contemplating a similar project.

Response Time

Of the project aircraft, the T-28 was the only one I can ever recall actually meeting a take-off time specified by the operations director! In addition, I don't remember ever hearing the T-28 pilot reporting unforeseen ground delays-- something that occasionally plagued the others. All in all, the T-28 crew got the aircraft ready to go at least within the minimum lead time requested, and sometimes faster.

Timely Positioning of the Aircraft

This one is always the toughest. I recall in 1989 the operations directors were consistently slow in giving the directive to fly, resulting in lost opportunities. In the NDTE, we did much better, partly because we were aware of our previous predilection for procrastination, and partly because there were so many storms it was hard to launch when there wasn't something worth penetrating. The one aspect of the T-28 operations that bothered me was that *we could only fly one flight per day*. There were a number of days on which the Citation and Duke flew a second time, but the T-28 had already flown so it sat on the ramp when the deep convection really got cooking. I understand the physical demands of thunderstorm flight in that aircraft, and will not suggest that the one flight restriction be lifted. However, with two pilots like Dan Custis and Charlie Summers, one might add a *two-pilot option* to the formula. Costs of course would escalate-- and perhaps Dan and Charlie would need to be persuaded. Quick review of the NDTE aircraft missions reveal that second flights were initiated on four days-- all among the very best days-- and perhaps would have been ordered on others had the T-28 been available. What would this expanded data set be worth, for only the cost of a second pilot?

It's just a thought.

All in all, a very successful effort, with a solid data base to show for it. Please extend my thanks to the entire crew, and Dan and Charlie when you next see them.

Sincerely,

Bruce A. Boe
Director