Report SDSMT/IAS/R-91/01 March 1991

ANNUAL PROGRESS REPORT ON T-28 AIRCRAFT FACILITY COOPERATIVE AGREEMENT (ATM-8620145)

By: Andrew G. Detwiler and Paul L. Smith

Prepared for:

Centers and Facilities Section
Division of Atmospheric Sciences
National Science Foundation
1800 G Street, N.W.
Washington, DC 20550

Cooperative Agreement No. ATM-8620145

Institute of Atmospheric Sciences

South Dakota School of Mines and Technology

501 E. St. Joseph Street

Rapid City, South Dakota 57701-3995

ABSTRACT

This is the annual progress report required under the terms of Cooperative Agreement No. ATM-8620145 between the National Science Foundation (NSF) and the South Dakota School of Mines and Technology (SDSM&T). The agreement provides for the operation of the SDSM&T armored T-28 meteorological research aircraft as a national facility for investigations into cloud, thunderstorm, and hailstorm processes. This report covers the period 16 February 1990 through 15 February 1991. During this period, there were no major convective-storm field projects in the continental United States and therefore no projects requiring the services of the T-28. Major facility efforts were directed toward instrumentation refurbishment, upgrade, and calibration, in preparation for two major field projects scheduled for 1991. This work included a series of intercomparison flights to establish aircraft form factors for in situ electric field measurements, installation of a Global Positioning System (GPS) receiver for accurate aircraft tracking, and installation and testing of a new digital telemetry system. Substantial scientific data analysis and reporting also took place during the period.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1. INTRODUCTION

This annual progress report on T-28 research aircraft facility activities under Cooperative Agreement No. ATM-8620145 covers the period 16 February 1990 through 15 February 1991. During this fourth and final year of the current agreement, efforts were directed towards preparing for support of two field projects planned for 1991. Each project requires refinements of existing instrumentation and data analysis techniques.

One area in which extensive work was done was in the improvement of in situ electric field observations using the T-28. The aircraft had been used in the past for electric field measurement tasks in three projects. However, deductions of actual field values from the aircraft instrument readings were uncertain by at least a factor of two due to uncertainties in how the aircraft itself distorted the field as the measurements were being made. This problem was attacked by analyzing measurements made in special maneuvers and tests performed on flights during 1986 and 1989, and by performing a series of intercomparison flights with a well-calibrated aircraft operated by the New Mexico Institute of Mining and Technology (NMIMT).

A new data telemetry system acquired during the previous year of the agreement was installed and successfully tested. This system is compatible with telemetry systems flown on National Center for Atmospheric Research (NCAR) aircraft and the University of North Dakota (UND) Cessna Citation II, all of which have participated in field projects in the past with the T-28. A new GPS/LORAN navigation receiver was also installed recently, to provide improved aircraft tracking capabilities.

The precipitation-particle photography system built for the T-28 during the National Hail Research Experiment (NHRE) was removed from storage and has been undergoing refurbishment for use in the Convection and Precipitation/Electrification (CaPE) project in Florida in 1991. It has not been flown since 1983, and most of its components are at least 15 years old. Nevertheless, successful bench tests lead us to expect reliable performance this coming summer.

Summaries of some of the details of these and other activities are given in the following sections.

2. PROGRESS DURING THE YEAR

Facility personnel were busy with a variety of upgrade activities during the year. All major equipment acquisitions under the current agreement, save one, were completed prior to the beginning of this agreement year (see Table 1). Major effort in this year was directed toward completing installation and checkout of some of this equipment. The remaining acquisition, a GPS location system and a cockpit audio panel upgrade, was completed in January 1991, using cost-recovery money from T-28 participation in field projects in 1989. This equipment has been tested on only one flight to date, but appears to be working according to specifications. Nominal location accuracy for the GPS unit is 30 m when the signal from the satellites is not intentionally degraded by the Department of Defense (and it is not being degraded at this time).

TABLE 1

Major Equipment Upgrades During the Agreement Period

Data Acquisition System
Telemetry System
Ground Station Computer
New Underwing Instrumentation Pylons
Cockpit Audio Recorder
Rewiring
Repainting
Type A Propeller
QEC Kit
Solid-State Inverters
GPS System (current year)

A one-week trip was made to Socorro, New Mexico, for purposes of intercomparing airborne electric field measurements. This accounted for most of the flight activity during the year as summarized in Table 2.

TABLE 2

T-28 Flights - July 1990

Date	Flight No.	Time (h)	Purpose
12 July	524	2.2	Local test
22 July	525	1.9	Ferry to Pueblo, CO
22 July	526	1.6	Ferry to ABQ
23 July	527	0.7	Ferry to Socorro
23 July	528	1.4	Return to ABQ, local check
24 July	529	2.3	Intercomparison
25 July	530	1.8	Intercomparison
26 July	531	2.4	Intercomparison
28 July	532	1.8	Ferry to Pueblo
28 July	533	1.8	Ferry to RAP
Total		17.9	

2.1 Instrumentation Developments

The T-28 telemetry system, a Data Radio D48 G5S1SSSG, includes a 2 W transmitter and a receiver with a corresponding ground station, and currently operates on a frequency of 418 MHz. Data are transmitted as digital packets that are coded so they will be received by the appropriate receiving unit. A packet is re-sent until an acknowledgment is received by the aircraft unit that it has been received at the ground, thus minimizing loss of data due to noise or low signal strength. Multiple aircraft can share the same frequency without interfering with each other. Although the telemetry hardware does operate bidirectionally, the data system has not yet been appropriately configured, so at the moment data transfer is strictly air-to-ground. Data are currently sent as a string of ASCII numbers representing variables selected when the data system is booted prior to takeoff, at a sampling rate of once per second. The data are received on the ground and can be displayed on a PC in the form of a simulated strip chart. Aircraft position may also be displayed on a two-dimensional map using a hybrid of a track display program authored by Steve Hunyady of NMIMT. Work is in progress to provide for transmission of received data from the ground PC to other computers using standard modem protocol.

A Trimble TNL2000 GPS system was installed in the T-28 late in January. It was operated on the return flight from the vendor's shop in Bismarck, ND, and is in good working order, although it has not been rigorously tested. The unit has been shipped to Science Engineering Associates (SEA) to allow them to test an interface to our SEA-built data acquisition system. The current unit will be upgraded to Model TNL3000, which is a combination LORAN/GPS unit, when the LORAN circuitry becomes available from Trimble. (Trimble has been backlogged filling orders from the military for GPS units for use in the Persian Gulf conflict.)

The precipitation-particle camera designed by Theodore Cannon for use on the T-28 during the NHRE was flown only intermittently after NHRE. It has not been flown at all since a project in Switzerland in 1983. The unique capability of the camera is its optical system which unambiguously produces double images with liquid drops and single images of opaque ice particles. The ability to distinguish between ice and liquid precipitation particles is of great interest to participants in CaPE for two reasons. One is that multi-parameter radar remote sensing techniques theoretically capable of distinguishing particle phase will be tested and require in situ verification. Concerning the second, many theories of cloud electrification based on collisions between various classes of particles require accurate knowledge of particle phases, as well as sizes and concentrations, if they are to be properly tested by observations.

Recent bench tests show most of the camera system to be in reasonable working order. The film drive mechanism has been shipped to its original manufacturer for cleaning and lubrication.

A vortex temperature probe housing of the type pioneered by Vonnegut has been constructed and bench tested. Airborne testing has been delayed by the press of other work.

2.2 Measurement Developments

Much effort has gone into the analysis of some segments of data from PACE and the North Dakota Thunderstorm Project (NDTP) supported in 1989. Aside from the scientific objectives, one purpose was to monitor the performance of T-28 instrumentation and improve the interpretation of data derived from this instrumentation. Areas of concern include the effects of icing and wetting on the two temperature probes; elimination of noise introduced into the static pressure record (which feeds through to our vertical wind calculation); analysis and automated interpretation of data from the Particle Measuring Systems OAP-2D-C probe; suspiciously low FSSP particle counts that possibly result from severe icing on some penetrations; and interpretation of electric field measurements made using the T-28.

Analyses by Dennis Musil showed that the reverse-flow temperature probe carried on the T-28 appears to behave as do similar probes tested by Lawson and others (Lawson, 1988; Lawson and Cooper, 1990). When temperatures are above freezing there can be significant wetting of the temperature-sensing element within the reverse-flow housing. In some situations, the wetting is more severe on the reverse-flow probe than on the Rosemount total temperature probe also carried on the T-28. In addition to the anomalously low temperatures reported under these conditions, the T-28 reverse-flow probe can also indicate anomalously low temperatures (lower than the Rosemount probe temperatures) under heavy icing conditions. The cause of this effect, and how it might be corrected, is uncertain at the moment. Ice buildup on the probe housing may alter the airflow (and therefore the recovery coefficient), or it may directly cool the air reaching the temperature sensing element. Lawson's work did not extend to such severe conditions as those typically encountered by the T-28. Controlled testing in an icing tunnel might be the most appropriate way to further study this problem.

The static pressure recorded on the data acquisition system is the most important component of the calculation of vertical wind from T-28 measurements (Kopp, 1985). The rate of change of aircraft altitude, as computed from the change in static pressure, dominates the computation. Abrupt spurious changes in the recorded pressure values produce apparent sharp vertical motions of the type shown in Fig. 1. Ken Hartman, the Facility Programmer, has developed an automatic technique for recognizing and eliminating these artifacts based on a technique reported by Berthel (1987). Gary Johnson, the Facility Engineer, is also attempting to eliminate the noise in the recorded data with a hardware solution.

Hartman has nearly completed the transfer of the software for analyzing image data obtained with 2D PMS probes from a mini-computer to a PC so that such analyses can be carried out in the field. During the transfer process, he has been streamlining and improving the software and its user interface.

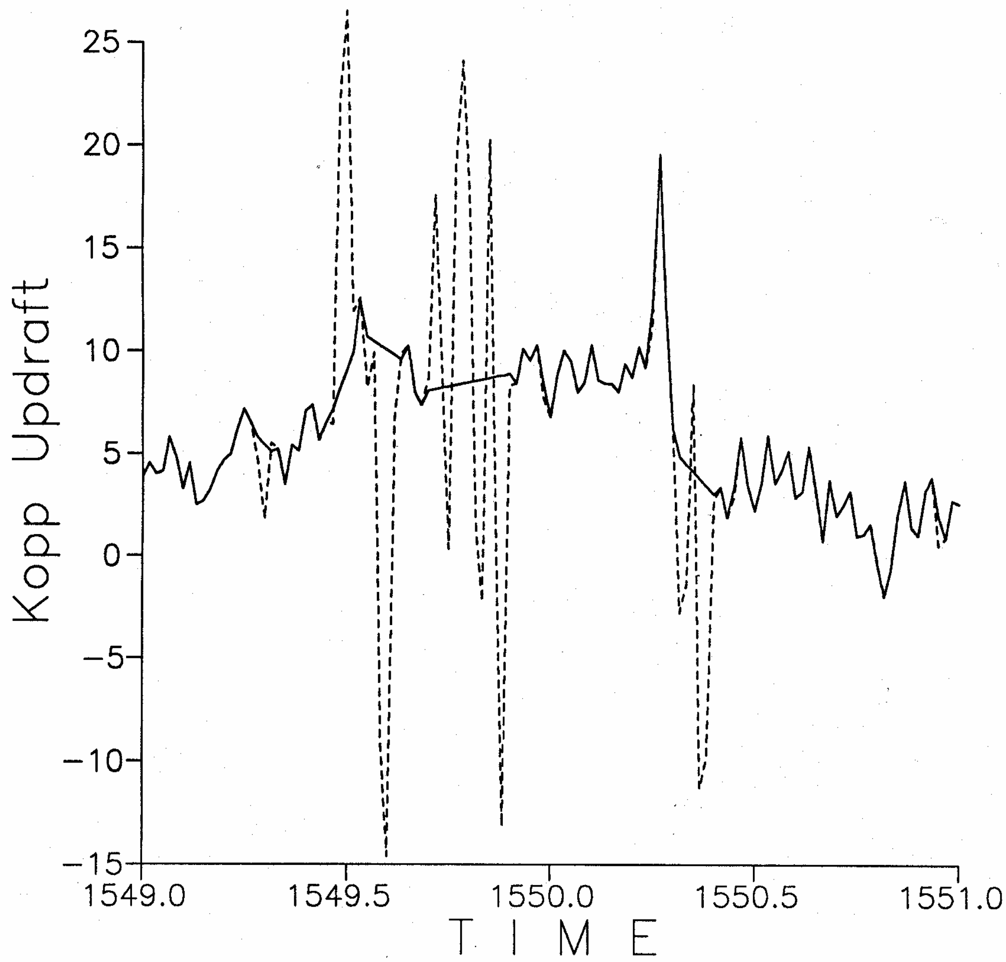

Fig. 1: Dashed line shows original updraft record while solid line shows updraft after automated removal of artifacts introduced by noise in the static pressure signal. These data were obtained during penetration of a hailstorm near Champaign, Illinois, on 25 May 1989.

Interpretation of droplet-size data (and therefore cloud liquid water concentration values) from the T-28 FSSP was greatly improved following a recalibration of the probe in 1988 by Droplet Measurement Technologies. Corrections for coincidence of particles in the probe beam and passage of undetected particles while the probe is recording data have been made for the past several years according to a semi-empirical approach based on the recorded probe activity. More sophisticated techniques have been developed (e.g., Brenguier, 1989). A review of T-28 data from 1989 suggests that uncertainty/inaccuracy in our droplet concentration measurements (which also affects the computation of liquid water concentration) may be more strongly affected by physical factors such as icing or fogging of the probe optical windows than by the computational technique. This question is the subject of ongoing investigation.

The area of measurement development that received the most attention during the year was electric field measurements from the T-28. During 1986 and 1989, the T-28 was equipped with borrowed rotating-shutter field mills mounted in the locations indicated in Fig. 2. These devices respond to the component of the local electric field normal to their faces. Their readings can be used with some care to make an estimate of the electric fields in various regions in and around thunderstorms. The ambient field that was present in the absence of the airplane making the measurement is corrupted by the multipolar field induced in the conducting aircraft by the ambient field as well as by the field produced by charge deposited on the aircraft itself by collisions with cloud and precipitation particles. The ionic effects of the engine exhaust may also play a role here. In order to make accurate estimates of the true ambient field, the various effects due to the presence of the aircraft must be calculable (e.g., Mazur et al., 1987; Jones, 1990).

Some of the information necessary for these calculations may be obtained from roll and pitch maneuvers in a constant (but perhaps unknown) ambient field while the aircraft is uncharged, and by charging the aircraft intentionally with an onboard power supply while flying in a region with a negligible ambient field. This type of testing had been done in the past with the T-28. The one crucial piece of information missing was a measurement of a known ambient field while the aircraft was uncharged. This information can be obtained by placing the aircraft in a known field on the ground using a large rig (Mazur et al., 1987), by using a small model and doing a laboratory analog study, or by making direct in-flight

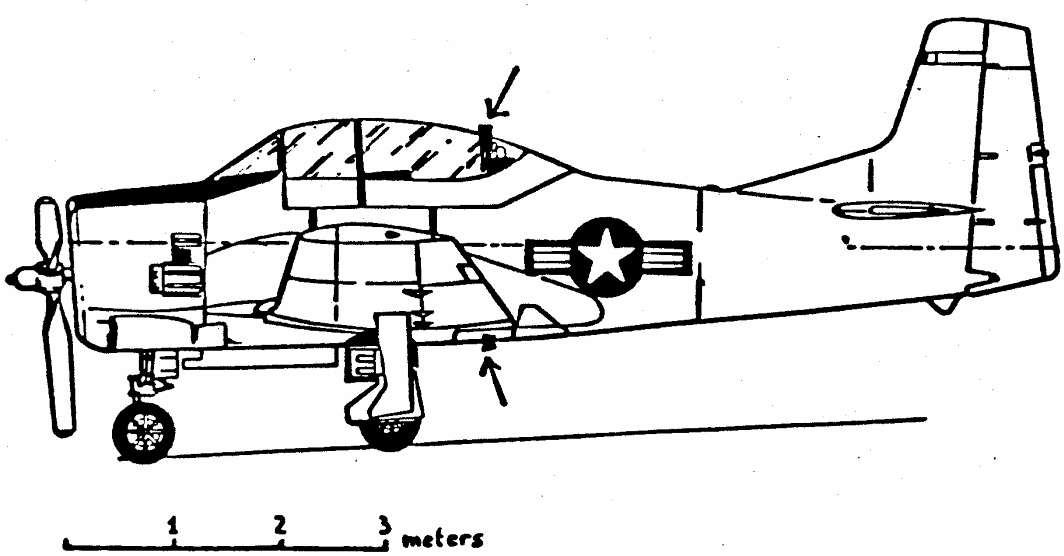

Fig. 2: The T-28 carries rotating-vane field mills mounted in its canopy and baggage bay door (arrows) and facing out from each wing tip.

comparison with a surface, tower, balloon, or airborne measurement made using a well-calibrated system.

The latter approach supplied the missing information for the T-28 this past summer. Three intercomparison flights were performed by the T-28 and the NMIMT SPTVAR under small thunderstorms near Socorro, New Mexico, during the last week of July 1990. Figure 3 is an example of simultaneous measurements of the vertical and transverse components of the electric field by the T-28 and SPTVAR while flying in close formation under a thunderstorm. They are shown to agree very closely when the proper form factors are applied to the T-28 measurements. A complete description of the intercomparison results is in preparation.

2.3 Software Development

In addition to the new developments in telemetry transmitting and display software and migration of 2D-probe analysis software to PC's described above, several other software projects were completed this year. A system for archiving data on the same cassette cartridges used by the aircraft data acquisition system was locally developed. In addition, improvements in the image-analysis software used to process foil impactor data are underway.

2.4 Data Exchanges and Information Requests

Inquiries concerning T-28 capabilities were received from several locations and duly answered. These included:

Aerosafe Company, Dublin, Ohio, concerning turbulence measurements in thunderstorms.

Earle Williams, MIT, concerning thermodynamic measurements in thunderstorms as indicators of the types of mixing occurring in them.

Airborne Research Associates, Weston, Massachusetts, concerning deployment of dropsondes from the T-28 into thunderstorms.

Anthony Holt, U. of Essex, England, concerning a possible project in Alberta.

Steven Rutledge, CSU, concerning studies of electrification in wintertime storms.

Keith Sheu, SAIC, Torrance, California, concerning general capabilities of the T-28 facility.

Facility staff have also worked closely with scientists organizing the two 1991 projects for which the T-28 has been allocated -- COPS, in Oklahoma, and CaPE, in Florida. These are discussed more fully below.

The T-28 Facility Scientist also gives approximately a dozen talks per year to local school groups concerning current severe storm research and general severe storm processes.

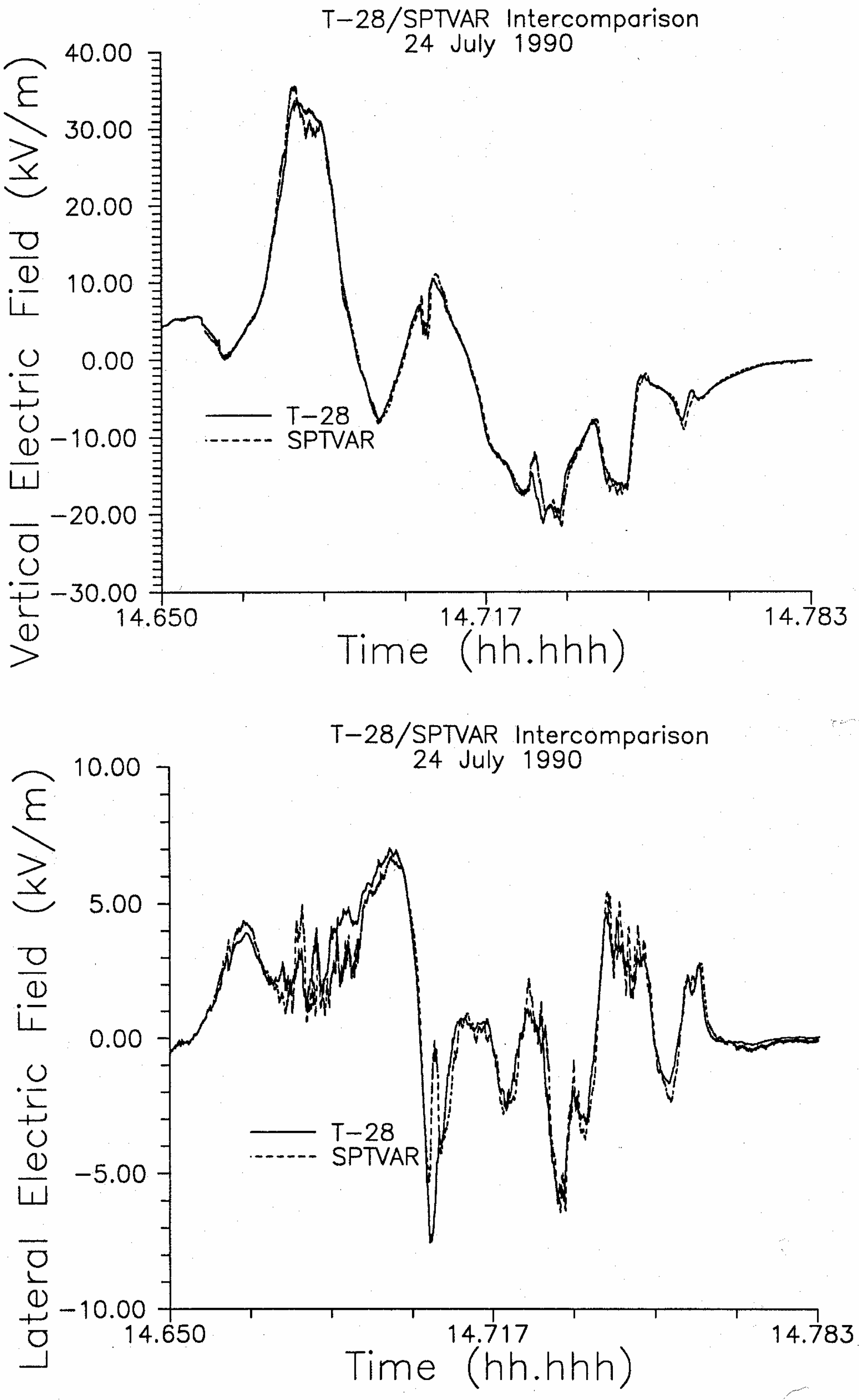

Fig. 3: Comparisons between electric field vertical (top) and lateral (bottom) components calculated from T-28 and SPTVAR electric-field mill readings during a close formation flight under a small thunderstorm.

3. FUTURE PLANS

A proposal to continue T-28 operation as a national facility following expiration of the current agreement on 14 May has been submitted to NSF. The proposal also requests some further upgrades to the facility capabilities.

The NSF Facilities Advisory Council has already allocated the T-28 to two field projects taking place after the expiration of the current agreement. The first is the Cooperative Oklahoma Profiler Studies project (COPS-91). The T-28 will be a participant in this extensive multiple-facility project from about 15 May through 15 June, in the Norman, Oklahoma, area. The requesting scientist, K. Aydin from Pennsylvania State University, will use T-28 data to validate inferences of hydrometeor type, phase, and size derived from multiparameter radar. The aircraft will also participate in mapping the electrical structure of mesoscale convective systems (along with other aircraft and balloon-borne systems, and ground measurements).

The second project is the Convection and Precipitation/Electrification (CaPE) experiment in Florida. The T-28 will be a participant in this large project from 8 July through 18 August. Its role will be the same in CaPE as in COPS-91 -- to provide in situ microphysical data to verify multiparameter radar remote microphysical retrievals, and provide measurements of electric fields in and around thunderstorms. In addition, it will be used to verify passive remote sensing results from several new NASA instruments flown on high altitude aircraft. The requesting scientists are Kevin Knupp, University of Alabama, Huntsville; V. Chandrasekar, Colorado State University; and Dennis Musil and Andrew Detwiler from SDSMT.

Future projects for which the T-28 has been mentioned as a desirable participant include the next NOAA Federal/State Cooperative Program summer field campaign, which may end up combining with a preliminary experiment organized by the STORM interest groups. Several states involved in the Federal/State Cooperative Program may combine forces on this project rather than running their own independent projects as has happened in the past. This campaign could not take place before 1992, and shows signs of slipping into 1993. The T-28 figures prominently in planning for the 1993 summer STORM field project. It has also been considered as a possible participant in the next major thunderstorm field program in the Langmuir Laboratory area in New Mexico. This will also probably be 1993 or later.

4. KEY PERSONNEL

No major changes in facility personnel have occurred in the past year.

5. PUBLICATIONS

Several publications involving work conducted under the T-28 facility cooperative agreement appeared during the year, and more are in progress. They are listed below, with indications of other sources of support where appropriate.

Published in Refereed Journals:

Detwiler, A. G., and V. Ramaswamy, 1990: Radiative heating profiles in simple cirrus cloud systems. J. Atmos. Sci., 47, 2167-2176.

Stith, J. L., A. G. Detwiler, R. F. Reinking and P. L. Smith, 1990: Investigating transport, mixing and the formation of ice in cumuli with gaseous tracer techniques. Atmos. Res., 25, 195-216. (Jointly supported by the North Dakota Federal/State Cooperative Program)

Submitted to Refereed Journals:

Huston, M. W., A. G. Detwiler, F. J. Kopp and J. L. Stith, 1990: Observations and model simulations of transport and precipitation development in a seeded cumulus congestus cloud. [Accepted for publication in J. Appl. Meteor.] (Jointly supported by the North Dakota Federal/State Cooperative Program)

Musil, D. J., S. A. Christopher, R. A. Deola and P. L. Smith, 1991: Some interior observations of southeastern Montana hailstorms. [Revised and resubmitted to J. Appl. Meteor.] (Supported mainly by another NSF grant)

Peterson, B. A., D. J. Musil and P. L. Smith, 1991: Computerized reduction of airborne foil impactor data. [Revised and resubmitted to J. Atmos. Oceanic Tech.] (Supported mainly by a NASA grant)

Declined:

Peterson, B. A., D. J. Musil and P. L. Smith, 1990: Computerized reduction of airborne foil impactor data from COHMEX thunderstorms. [Will be split into two papers and resubmitted, at referees' and editor's suggestion. Part I is Peterson et al., above.]

Presented at 1990 Conference on Cloud Physics:

Detwiler, A. G., N. C. Knight and A. J. Heymsfield, 1990: Measurement of liquid/solid mass loading in clouds. Preprints 1990 Conf. Cloud Physics, San Francisco, CA, Amer. Meteor. Soc., 318-323.

Peterson, B. A., D. J. Musil and P. L. Smith, 1990: Computerized reduction of airborne foil impactor data from COHMEX thunderstorms. Preprints 1990 Conf. Cloud Physics, San Francisco, CA, Amer. Meteor. Soc., 352-355. (Supported mainly by a NASA grant)

Presented at Severe Local Storms and Atmospheric Electricity Conferences:

Detwiler, A. G., J. H. Helsdon, Jr., and D. J. Musil, 1990: Evolution of a band of severe storms. Preprints Conf. Atmos. Elec., Kananaskis Provincial Park, Alberta, Canada, Amer. Meteor. Soc., 705-709. (Jointly supported by the North Dakota Federal/State Cooperative Program)

Musil, D. J., P. L. Smith and N. E. Westcott, 1990: Armored aircraft observations of a severe hailstorm in Illinois. Preprints 16th Conf. Severe Local Storms, Kananaskis Provincial Park, Alberta, Canada, Amer. Meteor. Soc., 485-488. (Jointly supported by the Illinois Federal/State Cooperative Program)

Presented at the Fourth Airborne Geoscience Workshop:

Detwiler, A. G., and P. L. Smith, 1991: Measurements of electric field using the armored T-28 aircraft. [29 Jan-1 Feb 1991, San Diego, CA]

Smith, P. L., 1991: University facilities for airborne geoscience. [29 Jan - 1 Feb 1991, San Diego, CA]

Report:

Detwiler, A. G., D. J. Musil and P. L. Smith, 1990: T-28 participation in the 1989 North Dakota Thunderstorm Project. Report SDSMT/IAS/R-90/05, Institute of Atmospheric Sciences, S. D. School of Mines and Technology, Rapid City, SD. 29 pp. + appendices.

M.S. Thesis:

Murtha, D. D., 1990: Reflectivity and microphysical structure of convective storms in the southeastern part of the United States. M.S. Thesis, Department of Meteorology, S.D. School of Mines and Technology, Rapid City, SD. 78 pp. (Supported mainly by a NASA grant)

Bulletin:

Detwiler, A. G., 1990: Armored T-28 research aircraft facility. Bulletin 90-1, Institute of Atmospheric Sciences, S.D. School of Mines and Technology, Rapid City, SD. 22 pp.

In addition, the outline of the procedure for requesting T-28 flight support was revised to reflect the recent changes in deployment cost arrangements and other changes.

The following paper contained T-28 data collected during the 1987 North Dakota Federal/State Cooperative Program field project:

Griffith, D. A., G. W. Wilkerson and D. A. Risch, 1990: Airborne observations of a summertime ground-based tracer release. J. Wea. Modif., 22, 43-48.

6. TRAVEL

The Facility Scientist traveled to Boulder, CO, 11-13 March 1990, to consult with coauthors of prospective conference papers. He and the Facility Manager participated in a CaPE planning meeting in Boulder, 3-4 April, and the Facility Manager traveled to another such meeting 7-9 November. The Facility Manager attended Advisory Panel meetings in Boulder 17-19 April and 28-31 October. He visited the University of Massachusetts in Amherst in late August to review work on millimeter-wave radars for atmospheric research, and visited NSF offices in Washington during the same trip.

The Facility Manager and Facility Scientist participated in the Severe Local Storms and Atmospheric Electricity conferences at Kananaskis Park, Alberta, in late October. The Facility Manager made panel and poster presentations at the 4th Airborne Geoscience Workshop in San Diego, 28 January - 1 February 1991. The pilot took the T-28 to Bismarck, ND, on 23 January for installation of new navigation equipment, and returned the aircraft to Rapid City a week later. The Facility Research Engineer attended the RF Expo West Conference in Santa Clara, CA, on 5-7 February 1991.

Five facility staff members, headed by the Facility Scientist, took part in the deployment to New Mexico which is discussed in Sec. 2.2.

7. REFERENCES

Berthel, R., 1987: A computer decision-making process for the elimination of noise from data. AFGL-TR-87-0118. Air Force Geophysics Laboratory, Hanscom AFB, MA 01731. 21 pp.

Brenguier, J. L., 1989: Coincidence and dead-time corrections for particle counters. Part II: High concentration measurements with an FSSP. J. Atmos. Ocean. Tech., 6, 585-598.

Jones, J. J., 1990: Electric fields acquired by airplanes penetrating thunderstorms. J. Geophys. Res., 95, 16589-16600.

Lawson, R. P., 1988: The measurement of temperature from an aircraft in cloud. Ph.D. dissertation, University of Wyoming. 336 pp.

Lawson, R. P., and W. A. Cooper, 1990: Performance of some airborne thermometers in clouds. J. Atmos. Ocean. Tech., 7, 480-494.

Mazur, V., L. H. Ruhnke and T. Rudolph, 1987: Effect of E-field mill location on accuracy of electric field measurements with instrumented aircraft. J. Geophys. Res., 92, 12013-12019.