Report SDSMT/IAS/R-98/04 December 1998

ANNUAL PROGRESS REPORT ON ARMORED T-28 AIRCRAFT FACILITY COOPERATIVE AGREEMENT (ATM-9618569)

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ABSTRACT

This is the annual progress report required under the terms of Cooperative Agreement No. ATM-9618569 between the National Science Foundation (NSF) and the South Dakota School of Mines and Technology (SDSMT). The 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. Field deployments as allocated by the NSF Facilities Advisory Council to support research projects are funded through other sources, including the NSF Lower Atmospheric Observing Facilities Deployment Pool. This report covers the period 16 December 1997 through 15 December 1998. During this period, the T-28 participated in the MOLAS project, an attempt to determine the propensity of propeller-driven aircraft to generate ice crystals in supercooled clouds, and a deployment to Colorado intended to test several instrumentation and data acquisition system upgrades on the T-28. In addition, research results from prior projects supported by the T-28 were described in research papers in refereed journals and presented at national conferences. Additional work in the areas of instrumentation refurbishments and upgrades, aircraft system improvements, 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-9618569 covers the period 16 December 1997 through 15 December 1998. The T-28 research project support activity during this period included the MOLAS investigation of the potential for propeller-driven aircraft to generate aircraft-produced ice particles (APIPs). A successful MOLAS flight was made in Colorado in February 1998. Another deployment to Colorado, in June 1998, was made to test the new data acquisition system on the T-28 along with new and refurbished instrumentation. Borrowed versions of instruments contemplated for further additions to the facility complement were also tested. Major work on the aircraft itself included repainting to arrest corrosion problems.

Subsequent sections present further details of these and related activities, along with plans for future facility activities.

2. PROGRESS DURING THE PERIOD

2.1 Project Support

2.1.1 MOLAS

The T-28 was again allocated to support the MOLAS investigations of aircraft-produced ice particles (APIPs) during the winter of 1997-98. The aircraft was deployed on a standby basis to Colorado during January and February 1998. The objective was to fly the aircraft through supercooled stratus clouds, using a variety of engine power and propeller speed settings to establish the envelope of operating conditions over which it may tend to generate APIPs. The deployment was requested by Dr. William Woodley of Woodley Weather Consultants, and funded by the NSF Lower Atmospheric Observing Facilities deployment pool.

The actual observations of any APIPs were to be obtained by a separate cloud physics aircraft, the University of Wyoming King Air, flying transects across the T-28 trail through the supercooled cloud. The T-28 was not required to carry any research instrumentation, but did carry SF_6 dispensing apparatus (furnished by North American Weather Consultants) to facilitate pinpointing the T-28 flight path. A flare rack provided by Weather Modification, Inc., was also carried to support a "piggyback" request from Dr. John Marwitz to test some hygroscopic cloud seeding flares.

Table 1 summarizes the 1998 T-28 flight activity associated with MOLAS. The aircraft was ferried to the Ft. Collins-Loveland Airport (FNL) in late January to be ready for flights on short notice into the supercooled stratus layers. A suc-

cessful flight was conducted on 16 February, though operating conditions did not allow complete exploration of the desired envelope of aircraft parameters. After the prospects for suitable clouds diminished in early March, the T-28 was returned to Rapid City.

Table 1
T-28 Flights in Support of MOLAS - 1998

Date (1998)	Flight No.	Time (hours)	Purpose
15 Jan	700	0.8	Local test
27 Jan	701	1.8	Ferry RAP → FNL
16 Feb	702	2.1	Research
7 Mar	703	1.6	Ferry FNL → RAP
	Total	6.3	

2.1.2 T-28 Systems Test

A T-28 deployment to test the new data acquisition system and some of the instrumentation newly acquired or soon-to-be-acquired was requested by Dr. Andrew Detwiler in his capacity as T-28 Facility Scientist. Deployment to Colorado where the T-28 flights could be directed with the aid of the CSU-CHILL radar was requested, and the deployment was funded by the NSF Lower Atmospheric Observing Facilities deployment pool.

The facility ground crew traveled via automobile to Loveland, Colorado, on 8 June, and the aircraft arrived the next morning at the Ft. Collins-Loveland Airport. After installation of computer and communications equipment at the CSU-CHILL site northeast of Greeley, as well as completion of the installation and interfacing of a borrowed Stratton Park Engineering Corporation (SPEC) High Volume Particle Sampler (HVPS) on the T-28, the first systems test flight was conducted on 11 June. Six more flights were conducted during the 19-day deployment (Table 2). The weather was characterized by relatively dry conditions, yet several interesting convective situations presented themselves within range of the CSU-CHILL radar where guidance could be provided for safe and focussed airborne microphysical sampling.

The new data system from Science Engineering Associates (SEA) proved to be a tremendous upgrade over the 9-year-old system it replaced. Its faster processor speed cleared up several problems that kept recurring with the old system. The most important advance, from a microphysical sampling point of view, is that the new system makes it possible to record massive amounts of excellent data from the Institute of Atmospheric Sciences (IAS) hail spectrometer imaging circuitry. The new system records data in flight on a hard-disk drive, a

mode of recording not heretofore attempted on the unpressurized and vibration-prone T-28. However, the hard drive functioned flawlessly throughout the deployment.

Table 2

Flights for T-28 Systems Test - 1998

Date (1998)	Flight No.	Time (hours)	Purpose
28 May	709	0.8	Local test
9 June	710	2.1	Ferry RAP → FNL
11 June	711	1.2	Research
12 June	712	1.1	Research
12 June	713	0.9	Research
17 June	714	1.0	Research
18 June	715	0.8	Aircraft test
21 June	716	1.3	Research
22 June	717	1.6	Research
25 June	718	1.6	Ferry FNL → RAP
	TOTAL	12.4	

The HVPS probe was on loan from Atmospheric Environment, Canada, to whom we are very grateful for the opportunity to evaluate this probe while interfaced to our new data system. This same probe had been flown on the T-28 in June, 1995, during the Verification of Origin of Rotation in Tornadoes Experiment (VORTEX), but in that deployment it was connected to its own independent data system using SPEC software and interface hardware. Interfacing the HVPS probe to the new SEA T-28 data system took a considerable amount of work, and SPEC and SEA provided helpful guidance throughout the period. By the end of the deployment, the probe was passing excellent data to the new data system. Figure 1 shows examples of HVPS images obtained during a hailstorm penetration at 4.5 km MSL and Figure 2 shows samples of images from the lower-resolution hail spectrometer for the same time interval.

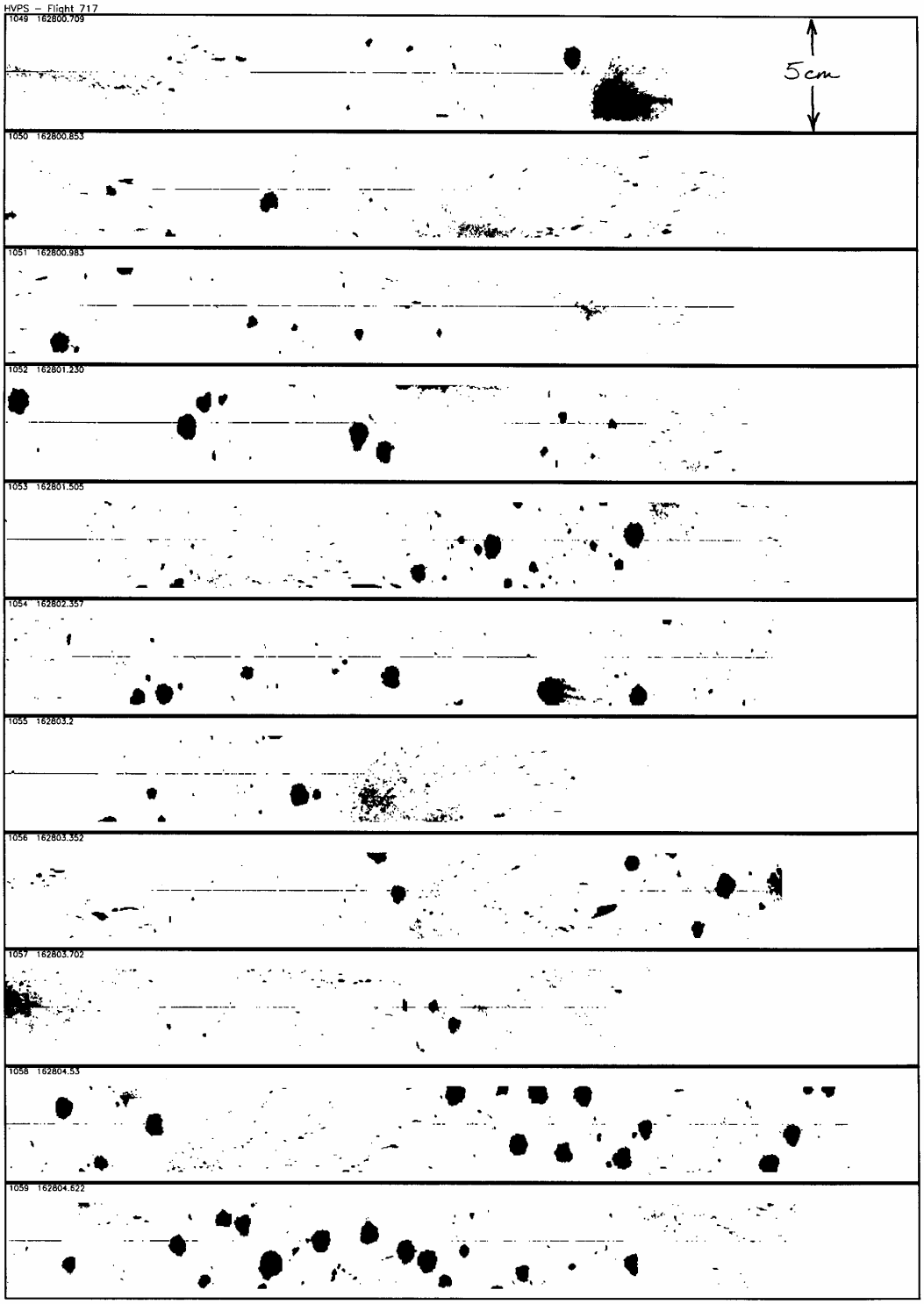

Figure 1. Particle images obtained from the HVPS for a four-second interval during penetration of a thunderstorm east of Denver, CO on 22 June 1998. The particles were observed in a downdraft (See Figure 3b). The optical array height is 5 cm, with image resolution of 0.2 mm.

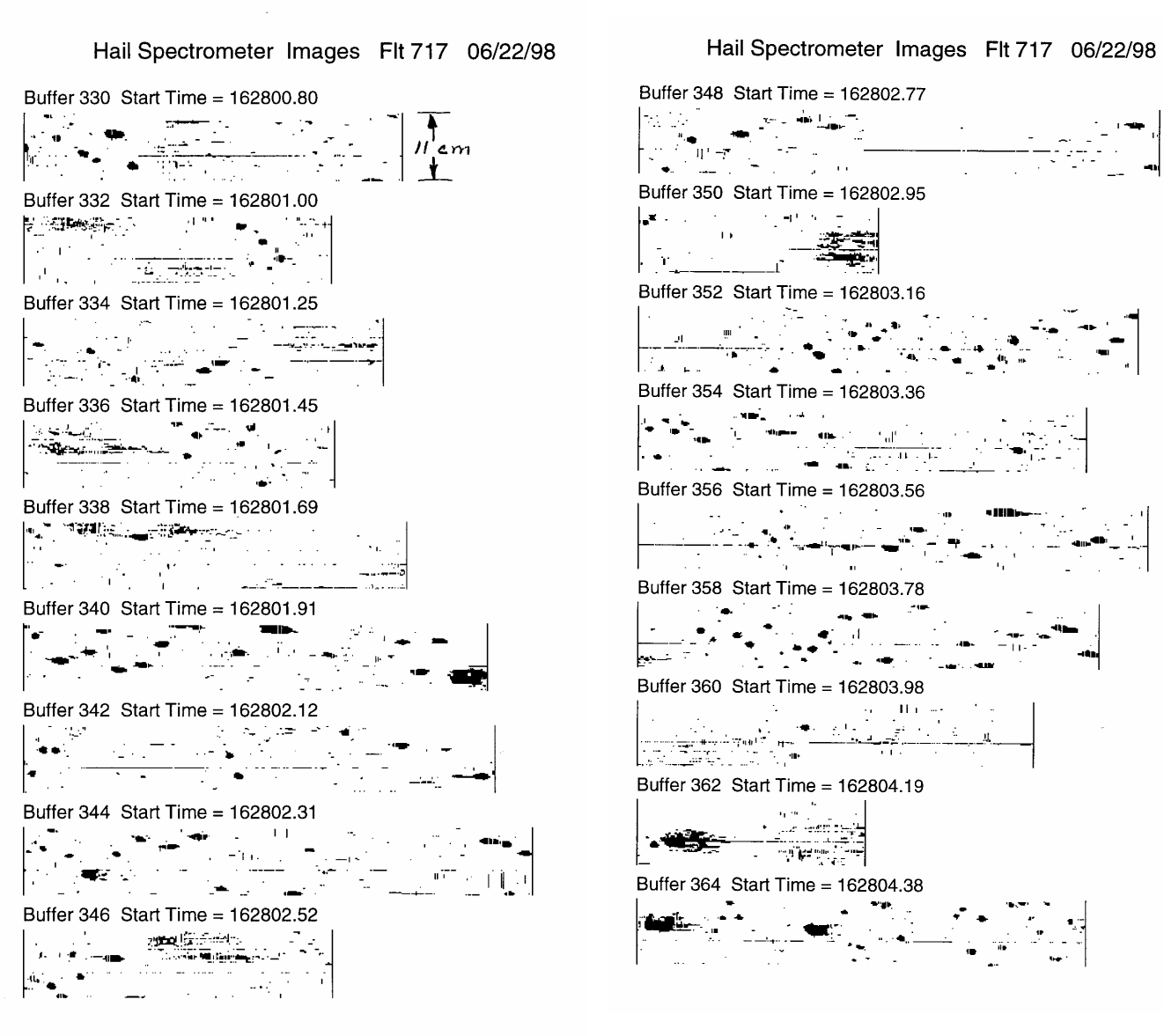

Figure 2. Particle images obtained from the hail spectrometer for the same interval as Figure 1. The array height is 11 cm, with image resolution of 0.9 mm.

Another important system on loan to the T-28 facility for this test flight series was a pair of pod-mounted electric field meter systems from the New Mexico Institute of Mining and Technology (NMIMT). Dr. Q. Mo joined the facility staff as a Postdoctoral Scientist with the goal of improving the measurement of ambient electric fields in mature-storm environments using the T-28. The pod-mounted system, which he developed with Dr. William Winn at NMIMT, was installed under the wings far away from the fuselage and thus from interference due to ions emitted from the propeller and carried in the engine exhaust. These ions influence the readings of the upward and downward-looking field meters mounted on

the T-28 fuselage, rendering the retrieval of the ambient field less certain. In addition, the 1997 intercomparison flights with the NMIMT Special Purpose Test Vehicle for Atmospheric Research (SPTVAR) aircraft showed that it is difficult to derive an estimate of the electric field component along the direction of flight using the then-existing T-28 system of two fuselage-mounted meters and three individual wing-mounted meters (Feind *et al.* 1998). Using data from the pod systems, Dr. Mo was able to show that much cleaner estimates of all three components of the ambient field could be obtained, compared to estimates derived from the existing system. However, the improved electric field estimates came at the expense of much-increased drag from the pod installation that limited the performance of the aircraft.

Also new to the T-28 on this deployment was a Droplet Measurement Technologies (DMT) cloud liquid water probe. This version of the King, or CSIRO, heated-coil liquid water probe performed very well. The original heated element survived a number of penetrations through regions containing substantial concentrations of relatively large graupel, but finally succumbed on the last flight, when one-inch hail was encountered. Figure 3a shows an example of liquid water measurements from the DMT probe during a thunderstorm penetration conducted on 22 June 1998. Updraft velocity for the same time interval is shown in Figure 3b. The particles imaged by the HVPS and hail spectrometer in Figures 1 and 2, respectively, were encountered within this interval.

Video recording was implemented on the T-28 for the first time during this deployment. A small video camera card was installed behind a plexiglass window added to the pylon on which the HVPS and DMT probes are mounted. The video signal was recorded, along with the cockpit audio and the windscreen microphone, by an 8-mm video recorder mounted in the rear cockpit. Excellent results were obtained up until the last research flight, during which heavy precipitation resulted in breakage of the window part way through the flight. Fortunately, the video camera card could be dried out and made to work again. Anticipated problems with icing of the window did result in loss of visual data after several passes were made through supercooled cloud. The continuous audio recording provided by the video recorder greatly facilitates post-flight analysis by scientists. The T-28 operates with a flight crew of one, and a busy pilot could only record very essential comments on the old on-demand audio-recording system. Now, however, the entire audio record (complete with a time indication) is available to T-28 users.

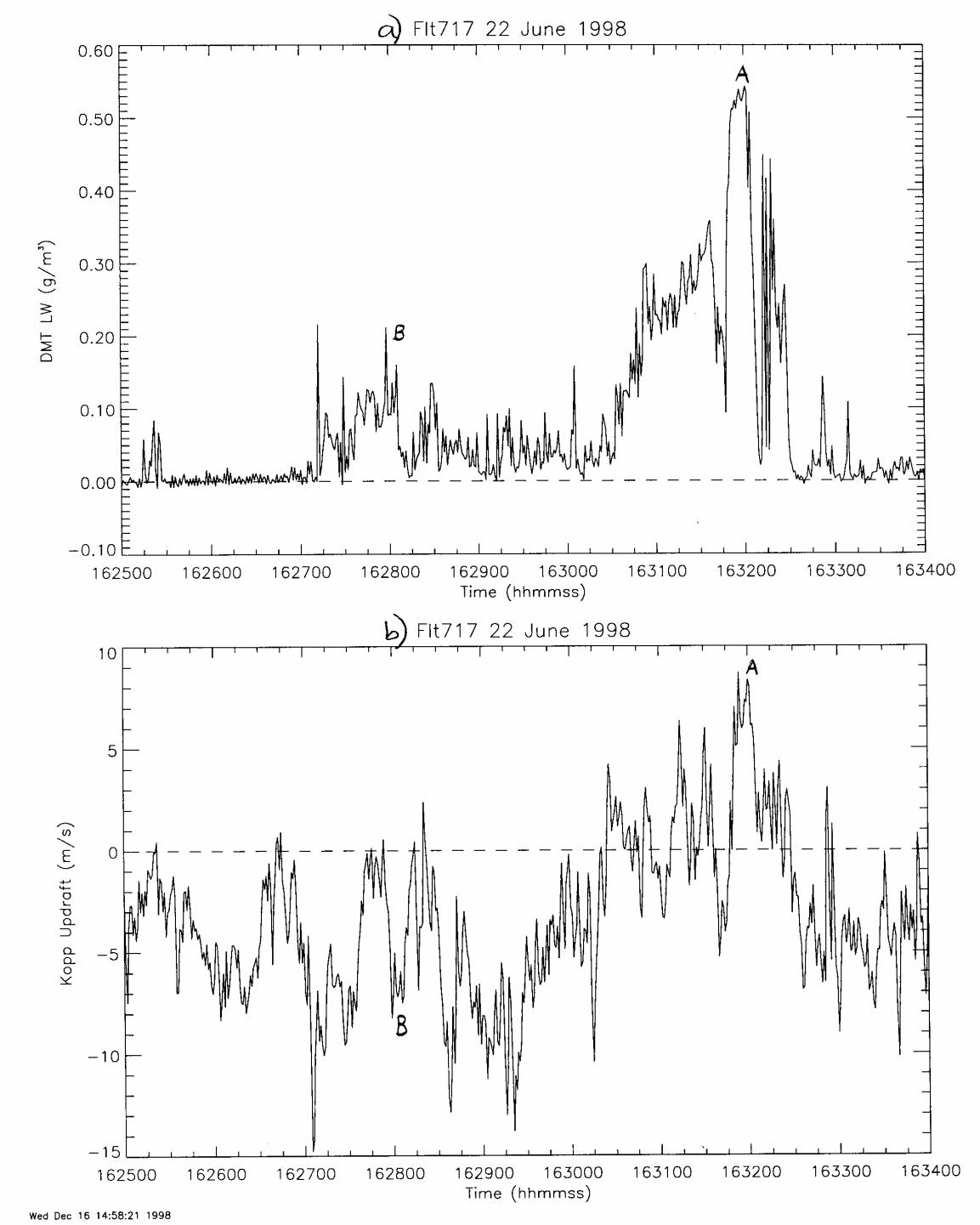

Figure 3. (a) Liquid water concentration (LWC) measured by Droplet Measurement Technologies (DMT) probe during T-28 penetration of a thunderstorm east of Denver, CO on 22 June 1998. (b) Updraft for the same time interval. "A" corresponds to a time period when maximum LWC coincided with maximum updrafts over the nine-minute interval from 162500 to 163400. "B" corresponds to the period when particles in Figures 1 and 2 were encountered.

The CSU-CHILL staff provided superb support for our test operations, while in the throes of trying to bring a second 10-cm Doppler radar on line during the same period. The CHILL crew is expert at interpreting the multiparameter CHILL display in real time to guide an aircraft or ground chase vehicles to regions with updrafts, precipitation shafts, hailswaths, and other storm features of interest. Their guidance contributed to our success in acquiring test data in a variety of environments.

As a result of this intense period of test flying, the T-28 facility staff returned home with a focussed list of action items needed to bring the T-28 into its next field deployment in top form. The results include knowledge of how to successfully mount and interface the new HVPS probe that is now under construction for the T-28, a newly-conceived plan for improving the electric field measurements without using the pods with their additional drag, plenty of HVPS image data with which to develop and test image analysis software so the data can be used in quantitative studies, plans for improved operation of the video camera, and an array of field-tested new and refurbished probes that are calibrated and in excellent working condition.

2.2 Instrumentation and Data System Developments

The plan to duplicate the NCAR RAF data system for the T-28 (Detwiler and Smith 1997) had to be abandoned when RAF advised us in January that resource limitations would make it impossible for them to provide the support needed to complete the design and implementation of the hardware and software configuration. Consequently, a new generation of the data system on the aircraft since 1989 was ordered from SEA. This new system upgraded the CPU from 286 to Pentium category, expanded the number of analog input channels available, and converted the recording medium from streaming tape to hard disk.

The instrumentation refurbishments and upgrades planned under the cooperative agreement are nearing completion (Table 3). Besides items previously discussed, an HVPS and another cylindrical electric field meter (of the same design as the existing meters on the aircraft) have been ordered. The Particle Measuring Systems (PMS) FSSP cloud droplet spectrometer has been overhauled and fitted with up-to-date optics and electronics. In addition, the laser in the hail spectrometer (as well as that in the 2D-C probe) has been replaced with a solid-state unit.

Table 3
T-28 Instrumentation Refurbishments and Upgrades

Item	Status
Cloud liquid water probe	New probe acquired and installed
FSSP cloud droplet probe	Refurbished and reinstalled
2D-C imaging probe	Refurbished and reinstalled
HVPS imaging probe	Unit for T-28 on order
Field mill system	Redesign complete; new mill on order
Video camera & recorder	Acquired and installed

Computer systems for post-flight data reduction were also upgraded.

2.3 Aircraft and Avionics Developments

The principal accomplishment in this area was to have the aircraft re-painted in an effort to arrest incipient corrosion. A generator that failed during the Colorado deployment is being replaced, and the starter is being overhauled at the same time. The magnetos were also replaced. Routine inspections were completed as scheduled, and the aircraft continues to be maintained under FAR Part 91 with an Airworthiness Certificate.

2.4 Administrative and Scientific Meetings

The T-28 facility was represented at the April and October 1998 meetings of the NSF Observing Facilities Advisory Panel by the Facility Manager. The Facility Postdoctoral Scientist also attended the April meeting. The Facility Manager also served during this period as the University Facility representative on the NSF LAOF Facilities Advisory Council.

The Facility Scientist participated in planning meetings for CESAR (see Sec. 3.1) in January and April. The Postdoctoral Scientist participated in the June deployment to Colorado with support under this agreement, and then returned the borrowed pod units to NMIMT. The Facility Scientist attended the American Meteorological Society's Conference on Cloud Physics in August. He also participated in a meeting on the National Aviation Weather Program at the University of Kansas in October. The Postdoctoral Scientist attended the 1998 Fall Meeting of the American Geophysical Union to present a paper on the T-28 electric-field measurements and discuss with colleagues future plans for CESAR (see Sec. 3.1) and other field projects.

2.5 Educational and Informational Activities

An article on the T-28 facility appeared in the Spring 1998 issue of the "SDSM&T Quarterly". The pilot led an information and flight safety meeting at the T-28 hangar in May with members of the local Experimental Aircraft Association chapter. The T-28 was put on static display at the Ellsworth Air Force Base Open House in September. A Graduate Research Assistant is completing an M.S. thesis based on a CaPE case study involving data from the T-28 and the NCAR sailplane.

2.6 Other Activities

An instrument test flight on 25 September focussed on further testing of the refurbished PMS 2D-C particle imaging probe.

Facility staff submitted input for the draft long-range plan for NSF Lower Atmospheric Observing Facilities, and then provided comments on draft versions of that plan. The Facility Manager also reviewed and provided comments on a draft of the National Aviation Weather Plan.

The T-28 facility staff revised and updated the request materials for requesting T-28 flight support. The staff also explored possible follow-on storm-penetrating aircraft platforms, with most interest focussing on the A-10 as a leading candidate.

3. PLANS FOR NEXT FUNDING YEAR

3.1 Projects to be Supported

A request for T-28 support of the LPEX project in the summer of 1999 was submitted for evaluation at the October 1998 meeting of the NSF Observing Facilities Advisory Panel (OFAP). Unfortunately, the massive resource demands of other projects planned for the same time frame made it impossible to provide the needed facilities and deployment pool support for LPEX. Consequently, the request was not considered by the OFAP, and the planning for LPEX has been deferred.

A request for a test of the T-28 capabilities for sampling trace gases has been received. The test program, which could be conducted locally in the summer of 1999, would examine issues related to inlet location, potential contamination by engine exhaust, and the like. Another request for T-28 support of the SEET project in New Mexico in the summer of 1999 has been received. These out-of-cycle requests will be processed for review at the Spring 1999 OFAP meeting.

The overview document for CESAR, a planned investigation of the relationship between hail and positive cloud-to-ground lightning discharges, has been

submitted to NSF and is now under review. The project (if approved) would take place in the summer of 2000 and would request support by the T-28 along with other NSF-sponsored observing facilities. Consideration is being given to merging the field operations of CESAR and LPEX.

3.2 Facility Refurbishments and Upgrades

We anticipate completing the instrumentation refurbishments and upgrades (see Sec. 2.2) during the coming year. Consideration is being given to possible further upgrades, including a gust boom for wind and turbulence measurements and a capability for sampling trace gases, that might be provided under South Dakota EPSCoR funding to enhance research capabilities.

3.3 Data Analysis Efforts

The T-28 facility staff will continue with data analysis and publication work as time and resources permit. Primary emphasis will be placed on completing analysis of data from COPS-91 and CaPE and organizing the results of the electric field mill system test flights into a brief journal manuscript. The manuscript will summarize the results of both the 1990 and 1997 SPTVAR/T-28 field meter calibration work. A review of the historical measurements of cloud liquid water made with the Johnson-Williams sensor will be submitted for publication. One flight during the 1998 T-28 systems test deployment produced aircraft and coordinated radar data that will provide a basis for a conference paper.

4. PERSONNEL

The key personnel indicated in Section I.10 of the Agreement as amended remain committed to the project at the levels indicated. Dr. Qixu Mo joined the facility as Postdoctoral Scientist in January.

5. PUBLICATION ACTIVITY

Journal Papers

Smith, P.L., D.J. Musil, A.G. Detwiler, and R. Ramachandran, 1999: Observations of mixed-phase precipitation within a CaPE Thunderstorm, *J. Appl. Meteor.,* (in press).

Detwiler, A.G. and H. Norment, 1999: The M-Meter: A simple airborne hydrometeor measurement instrument. (Submitted to *Journal of Atmospheric and Oceanic Technology*).

Conference Papers

Feind, R.E. and A.G. Detwiler: Intercomparison of T-28 J-W and King Probe cloud liquid water measurements: VORTEX/MIGHT, May and June 1995. *Conf. on Cloud Physics,* 17-21 Aug. 1998, Everett, WA, Amer. Meteor. Soc., 122-125.

Reports

Feind, R.E., Q. Mo, and A.G. Detwiler, 1998: Report on T-28 Electric Field Measurements and Their Calibration. Report 98-1, Institute of Atmospheric Sciences, South Dakota School of Mines and Technology, Rapid City, SD 57701, 179 pp.

Smith, P.L., 1998: Summary of T-28 participation in MOLAS, 1994-1998. Report 98-2, Institute of Atmospheric Sciences, South Dakota School of Mines and Technology, Rapid City, SD 57701, 4 pp.

Other Items

Detwiler, A.G., 1998: Scientific Overview of Cloud Electrification Studies using Aircraft and Radars (CESAR), 2000. Bulletin 98-1, Institute of Atmospheric Sciences, South Dakota School of Mines and Technology, Rapid City, SD 57701, 25 pp.

Papers by Other Authors Using T-28 Data

Ryzhkov, A.V., B.A. Gordon and D.S. Zrnic′, 1998: Polarimetric method for ice water content determination. *J. Appl. Meteorol.,* **37**, 125-134.

6. Current and Pending Support

See GPG Section II.D.8 for guidance on information to include on this form.)

The following information should be provided for each investigator and other senior personnel. Failure to provide this information may delay consideration of this proposal.

Investigator: Andrew G. Detwiler	Other agencies (including NSF) to which this proposal has been/will be submitted.

Support: ☒ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title:

Further Investigation of Microphysical, Kinematic, and Electrical Characteristics of CaPE Thunderstorms

Source of Support: National Science Foundation

Total Award Amount: $270,000 Total Award Period Covered: 1 Dec 1995-30 Nov 1999

Location of Project: Rapid City, SD

Person-Months Per Year Committed to the Project. Cal: 1.6 mo. Acad: Sumr:

Support: ☒ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title:

Armored T-28 Aircraft Facility for Research Requiring Thunderstorm Penetrations

Source of Support: National Science Foundation

Total Award Amount: $858,894 Total Award Period Covered: 15 Mar 1997-29 Feb 2000

Location of Project: Rapid City, SD

Person-Months Per Year Committed to the Project. Cal: 6 mo.* Acad: Sumr: * cost-sharing

Support: ☐ Current ☒ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title:

Drought Monitoring Technology: Technology Transfer and Relationship to Crop Stress

Source of Support: NASA

Total Award Amount: $187,000 Total Award Period Covered: 1 Jan 1999-31 Dec 2001

Location of Project: Rapid City, SD

Person-Months Per Year Committed to the Project. Cal: .5 mo. Acad: Sumr:

Support: ☐Current ☒Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title:

Remote Sensing to Improve Precision Farming Management Decisions

Source of Support: NASA

Total Award Amount: $132,000 Total Award Period Covered: 1 July 1999-30 June 2002

Location of Project: Rapid City, SD

Person-Months Per Year Committed to the Project. Cal: .50 mo. Acad: Sumr:

*If this project has previously been funded by another agency, please list and furnish information for immediately preceding funding period.

NSF Form 1239 (7/95) USE ADDITIONAL SHEETS AS NECESSARY

Current and Pending Support

See GPG Section II.D.8 for guidance on information to include on this form.)

The following information should be provided for each investigator and other senior personnel. Failure to provide this information may delay consideration of this proposal.

Investigator: Paul L. Smith

Other agencies (including NSF) to which this proposal has been/will be submitted.

Support: ☒ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title:

Further Investigation of Microphysical, Kinematic, and Electrical Characteristics of CaPE Thunderstorms

Source of Support: National Science Foundation

Total Award Amount: $270,000 Total Award Period Covered: 1 Dec 1995-30 Nov 1999

Location of Project: Rapid City, SD

Person-Months Per Year Committed to the Project. Cal: 1.8 mo. Acad: Sumr:

Support: ☒ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title:

Armored T-28 Aircraft Facility for Research Requiring Thunderstorm Penetrations

Source of Support: National Science Foundation

Total Award Amount: $858,894 Total Award Period Covered: 15 Mar 1997-29 Feb 2000

Location of Project: Rapid City, SD

Person-Months Per Year Committed to the Project. Cal: 1.5 mo. Acad: Sumr:

Support: ☒ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title:

Adaptive Threshold Approaches for Determining ATI from Satellite Data to Estimate Rain Volumes

Source of Support: NASA

Total Award Amount: $743,327 Total Award Period Covered: 1 May 1995-30 April 1999

Location of Project: Rapid City, SD

Person-Months Per Year Committed to the Project. Cal: 0 mo. Acad: Sumr:

Support: ☒Current ☐Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title: Upper Missouri River Basin Project

Source of Support: NASA

Total Award Amount: $800,000 Total Award Period Covered: 1 Feb 1998-31 Jan 2000

Location of Project: Rapid City, SD

Person-Months Per Year Committed to the Project. Cal: 1.8 mo. Acad: Sumr:

Support: ☒ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title: Kwajalein Radar Evaluation and Calibration Work

Source of Support: Aeromet Inc. (U.S. Army)

Total Award Amount: $26,000 Total Award Period Covered: 30 December 1997-30 June 1999

Location of Project: Rapid City, SD

Person-Months Per Year Committed to the Project. Cal: 1.5 Acad: Sumr:

*If this project has previously been funded by another agency, please list and furnish information for immediately preceding funding period.

NSF Form 1239 (7/95) USE ADDITIONAL SHEETS AS NECESSARY

7. COST SHARING FUNDS

As of 1 December 1998, SDSM&T has provided $108,550 in cost-sharing expenditures in support of this Cooperative Agreement. We anticipate providing another $15,000 by 28 February 1999.

8. RESIDUAL FUNDS

We anticipate a residual balance at 28 February 1999 of about $75,000. This is almost entirely in the Salaries and Benefits category, with associated Indirect Costs. The unexpended funds in these categories have resulted from the relatively slow pace of T-28 deployment over the period of this agreement.

There is a current residual balance of about $8,000 in the account for the MOLAS deployment.

9. COST RECOVERY FUNDS

No cost recovery funds were generated during the period covered by this report. At this time we anticipate no cost-recovery activity during the next funding year.

10. REFERENCES

Detwiler, A.G. and P.L. Smith, 1997: Annual Progress Report on Armored T-28 Aircraft Facility Cooperative Agreement. IAS Report 97/02, prepared for Div. of Atmospheric Sciences, NSF, Sept. 1997, 17 pp.

Feind, R.E., Q. Mo, and A.G. Detwiler, 1998: Report on T-28 Electric Field Measurements and Their Calibration. IAS Report 98/01, prepared for Division of Atmospheric Sciences, National Science Foundation, Sept. 1998, 179 pgs.