Report 75-7 May 1975

FINAL REPORT ON T-28 ARMORED AIRCRAFT DURING THE PERIOD 1 MARCH 1974 - 28 FEBRUARY 1975

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Prepared for:

National Science Foundation
Washington, D. C. 20550

Prime Contract No. NSF-C460

National Hail Research Experiment
National Center for Atmospheric Research
P. O. Box 3000
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Subcontract No. NCAR 182-71

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ABSTRACT

A North American T-28 aircraft modified for use as a hailstorm penetration research aircraft proved its value as a research tool during the 1972 and 1973 NHRE field programs.

This report describes the T-28 project from March 1974 through February 1975. The aircraft was not flown during the 1974 NHRE field project due to budgetary constraints within NHRE.

The contract period was spent in designing and installing new or improved equipment on the T-28 aircraft and in the analysis of data from previous years.

Principal improvements during the period include installation of new primary and secondary data recorders, both of which are capable of recording scientific data as long as the aircraft can remain aloft. New instruments include airspeed pressure transducer, accelerometer, reverse flow platinum resistance thermometer, and a device for recording aircraft heading. In addition, the preliminary steps have been taken to equip the T-28 with a Cannon camera capable of detecting hydrometeors down to 80 μm diameter and Knollenberg probes to measure particle size from 3 to 800 μm in diameter. Work continued on the development of the laser hail sensor and toward the mounting of this device on the T-28. A complete listing of the instrument configuration as planned for the 1975 field season is provided.

Considerable progress was made in the analysis of the 1972 and 1973 data and its correlation with data obtained by other instrument systems on the NHRE program including radar equipment. The principal finding is that liquid water concentrations are generally low in and near the high radar reflectivity zones near the -15C level. The updraft regions in hailstorms are often found to contain significant quantities of supercooled liquid water, with the maximum concentration along the edges of the updrafts. Papers describing these findings are attached to the report as appendices.

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1. INTRODUCTION

This report covers work on the T-28 project during the period 1 March 1974 to 28 February 1975. Because of budget constraints on the NHRE project the T-28 was not operated in the field during the 1974 season. Due to the lack of field operations by the T-28, the objectives stated in the work plan were of necessity designed to emphasize data analysis. However, the aircraft was to be exercised for approximately two hours per month to keep it in good mechanical condition.

The stated objectives as listed in our letter proposal/work statement of 22 February 1974 were to study:

1) Measurements of vertical motions in hail regions.

2) Composition of high reflectivity zones.

3) Ice-water budgets.

4) Model comparisons.

5) Testing platform for special measurements.

The plan was to concentrate on the analysis of previous data to progress toward the above stated goals. The development of an instrumentation system to better enable the T-28 system to accomplish the above stated goals was to be one of the achievements during the contract period.

2. INSTRUMENTATION

The T-28 instrumentation took a giant stride forward in both quantity and quality during this contract period. The new recording system and the various new sensors should enable the T-28 system to better answer some of the germane questions relating to the internal structure of hailstorms.

The instrumentation planned for the 1975 season is listed in Table 1. Each new piece of equipment not previously described or which has changed appreciably is described in detail. The 1975 field season is planned as a test season for these new instruments.

2.1 The Recording Systems

The data system has a primary and secondary data recorder, both of which are capable of recording scientific data as long as the airplane can stay airborne. The primary data recorder uses computer compatible, seven-track magnetic tape and records all variables once each second. Some variables are recorded twice each second to provide the data density required for certain types of analysis.

The secondary data recorder will record everything the primary system records except the digital channels. It also records three audio channels. The three audio channels are for pilot's comments, hail sound and all incoming and outgoing radio transmissions. A small stereo voice recorder is carried as a backup to assure that the important pilot's comments and hail sounds are recorded. A fourth recorder will be carried during 1975 and subsequent seasons to record data from the Knollenberg probes now being added, since the volume of data from these probes far exceeds the available capacity of our present recorder.

Instruments such as cameras, the foil impactor, and the precipitation sampler, of course, have their own data recording. However, special event codes recorded with the other data enable a precise correlation of this special data with the remainder of the data gathered on magnetic tape.

2.2 New and Modified Equipment

2.2.1 Pressure altitude

A Rosemount Model 1301-A-4-B temperature controlled absolute pressure transducer will be used to derive very accurate pressure altitudes. It is planned to attempt to record the output of this device in a high resolution mode to acquire updraft velocities.

TABLE 1

List of data recorded and scientific equipment used on the T-28

Recorder Data Channel	Parameter	Equipment Used
--	Time	Primary data system internal master clock
0	Pressure Altitude (Rate-of-climb)	Rosemount Model 1301-A-4-B temperature controlled absolute pressure transducer amplified for rate-of-climb calculations
1	Indicated Airspeed (Turbulence)	Rosemount Model 1301-D-1-B temperature controlled differential pressure transducer
2	Instantaneous Acceleration	Humphrey Model SA09-D-0101-1 vertically stabilized accelerometer
3	Pressure Altitude	Rosemount Model 1301-A-4-B temperature controlled absolute pressure transducer
4	Pressure Altitude	Ball Model EX-210-B absolute pressure transducer
5	Temperature	Rosemount Model 102AU2AP total temperature probe
6	Temperature	NCAR platinum resistance reverse flow
7	Rate-of-climb	Ball Model 101A variometer
8	Manifold Pressure	Giannini Model 45218YE pressure transducer
9	Heading	IAS designed device to enable recording of aircraft heading
10	VOR	MetroData Systems, Inc., M-8 used to record from a Narco MK-12

TABLE 1 (Continued)

Recorder Data Channel	Parameter	Equipment Used
11	DME	MetroData Systems, Inc., M-8 used to record from a Narco UDI-2ARD
12	DME	MetroData Systems, Inc., M-8 used to record from a Narco UDI-4
13	Liquid Water Content	Johnson-Williams liquid water content probe
14	Icing Rate	Rosemount Model 871 BG icing rate probe
15	True Airspeed	NCAR designed true airspeed computer
16	Regulated 5 Volts	5 volt power supply
17	Cabin Temperature	IAS designed device used for instrumentation trouble shooting
18	Aircraft Roll Angle	Humphrey Model SA09-0101-1
19	Aircraft Pitch Angle	Humphrey Model SA09-0101-1
20	Pressure altitude (Rate-of-climb)	Rosemount Model 1301-A-4-B temperature controlled absolute pressure transducer amplified for rate-of-climb calculations
21	Indicated Airspeed (Turbulence)	Rosemount Model 1301-D-1-B temperature controlled differential pressure transducer
22	Instantaneous Acceleration	Humphrey Model SA09-0101-1 vertically stabilized accelerometer
23	Maximum Acceleration	Humphrey Model SA09-0101-1 vertically stabilized accelerometer
24 BCD digits	Hail Sensor	IAS designed laser hail sensor to detect, size, and count hailstones
3 BCD digits	Event Codes (9)	IAS designed digital event codes

TABLE 1 (Continued)

Recorder Data Channel	Parameter	Equipment Used
3 BCD digits	Frame Count	Frame counter for Cannon particle camera
--	Hydrometeors	Williamson Aircraft Company foil impactor (250 µm - 20 mm dia.)
--	Precipitation	NCAR designed precipitation sampler to gather samples for laboratory analysis
--	Voice Recorder	Hewlett-Packard Model 3960 A four-channel instrumentation recorder 1) Pilot's comments 2) Radio conversations 3) Hail sounds 4) Secondary data recorder
--	Hydrometeor	Two Knollenberg probes 1) OAP-2D (25-800 µm dia.) 2) ASP-100 (3-45 µm dia.)
--	Hydrometeor	Cannon particle camera
--	Visual Cloud	Super 8-mm movie camera with automatic exposure and remote control

2.2.2 Time

As part of the new data recording system a new time source will be added. This single source of very accurate time will be used as a time reference on all the data systems aboard the T-28.

2.2.3 Indicated airspeed

A Rosemount Model 1301-D-1-B temperature controlled differential pressure transducer will be used to acquire an accurate indicated airspeed. The indicated airspeed is used in the calculation of true airspeed as well as in the calculation of turbulence. The new pressure transducer will enable much better calculations of the above values.

2.2.4 Accelerometer

A Humphrey Model SA09-0101-1 gyro stabilized vertical accelerometer will be added to the package. We plan to record the maximum vertical acceleration during each one second sampling period along with the actual accelerometer values twice each second. The accelerometer has a range of ± 2 G's from the nominal 1 G value. In addition, the stabilized accelerometer will output pitch and roll angles which we plan to record.

2.2.5 Temperature

A new platinum resistance reverse flow temperature sensing device has been designed and constructed by NCAR for the T-28. This device has the ability to measure temperature in clouds by using the reverse flow technique with the very fast time response inherent in platinum resistance temperature sensors.

2.2.6 Aircraft heading

Engineers on the Institute of Atmospheric Sciences staff have designed a device to record the aircraft's heading from the aircraft's compass system. Combining this with the true airspeed and the track radar derived track and ground speed, we will be able to derive a reasonable estimate of horizontal winds.

2.2.7 DME

We plan to record the distance from two DME stations aboard the T-28. This will include the addition of a second DME system and related recording capability. We also record a single VOR to remove the location ambiguity. However, we count on the track radar for a precise location of the aircraft and merely use the VOR/DME system as a backup.

2.2.8 Knollenberg probes

We plan to add two Knollenberg probes and all the related data recording equipment. This system consists of an OAP-2D probe which measures particles in the size range from 25 to 800 μm diameter and is able to distinguish ice particles from water droplets when the hydrometeors are larger than 100 μm diameter. This should answer a vital cloud physics question concerning the ice-water composition of hailstorms. The other probe is to be an ASP-100 which will count and size droplets with diameters between 3 and 45 μm. This probe will enable us for the first time to size and count particles smaller than 50 μm diameter. A separate recorder is included as part of the package to enable recording the tremendous quantities of data generated by these probes. Time will be taken from the master clock to enable relating these data to the other data recorded in the airplane. A true airspeed computer will be built to provide the information required to compute the volume sampled. This true airspeed information along with the temperature and the altitude (pressure) will be recorded on the Knollenberg recording system so that the data can stand alone.

2.2.9 Hail sensor

A laser hail sensor is being built by engineers and technicians at the Institute of Atmospheric Sciences. This device will use the shadow graph principle on an array of photo transistors to detect, count and size hailstones passing through its sampling volume of about 12 m^3 s^{-1}. The device has a resolution of about 1 mm and the logic is such that it assumes that all particles larger than 5 mm are hailstones and counts them as such, ignoring all particles smaller than 5 mm diameter.

2.2.10 Particle camera

A Cannon particle camera is being designed for the T-28 to photograph the small hydrometeors that have the potential of acting as hail embryos and making the all important ice-water determination on these particles. At this point we do not know the exact sample volume attainable or the hydrometeor sizes that the device will be able to photograph. These values will be determined as the instrument is developed and tested on the T-28.

3. THE AIRCRAFT

With no field season during this contract period the T-28 has seen limited activity. Table 2 summarizes the flights made with the T-28 during the contract period, most of which were made for preventive maintenance reasons.

The work done on the airplane during the contract period was primarily in the line of preventive maintenance. There were four engine cylinders replaced due to hail damage from the 1972 and 1973 seasons. These cylinders were replaced with overhauled units that had new cooling fins installed to decrease the possibility of significant future hail damage to this part of the airplane. The cylinder cooling fins have proven to be the most vulnerable part of the airplane to hail damage.

Substantial rear seat area and instrumentation bay area modification was required for the installation of new equipment. Most of this work was done as a result of the relocation of the data recording system into the rear seat and the removal of all the remaining controls and standard equipment from the rear seat to make room for the data package. The instrumentation bay modification was to accommodate the Knollenberg data recording package.

Normal maintenance and FAA required inspections were performed as necessary during the contract period.

TABLE 2

Summary of T-28 flights

Date	Flight Time (hours)	Purpose
24 May 1974	1.2	Maintenance test
22 August 1974	1.0	Maintenance test
13 September 1974	1.2	Maintenance test
18 September 1974	1.3	Johnson-Williams airflow test
20 September 1974	2.0	Trip to Denver to see Stanley
22 September 1974	1.9	Aviation about T-28 modifications
7 November 1974	1.2	Maintenance test
5 December 1974	1.2	Maintenance test
Total	11.0	

4. RESEARCH PROGRESS

Analysis efforts during the reporting period were concentrated on the data gathered during the 1972 and 1973 field seasons. Specific topics included a study relating T-28 observations to detailed radar data from hailstorms penetrated in 1972 (Sand, 1974); analysis of foil impactor data from penetrations made during the 1973 field season (May, 1974); and development of an airborne optical hailstorm disdrometer to measure number concentrations and size distributions of hailstones between 0.5 cm and 4 cm diameter (Shaw, 1974).

The above topics were covered in Master's degree theses and submitted to your office as technical reports. Portions of these reports were selected, amplified, and presented at various conferences during the fall of 1974. Preprints of the conference papers are included as Appendices B - E. Work in the above areas is continuing.

T-28 observations during 1972 (Sand *et al.*, 1974b) showed the high reflectivity zones of hailstorms to be made up almost entirely of ice, with little or no airframe icing, response of the Johnson-Williams liquid water probe, or other indications of the presence of liquid. Furthermore the most severe turbulence encountered during penetrations was consistently found to be associated with the strongest radar reflectivity (Sand *et al.*, 1974a).

On the other hand, the strong updrafts contained enough supercooled water to produce moderate to severe airframe icing as well as producing indications of abundant small liquid particles on the Johnson-Williams device and a Rosemount icing rate probe (Musil and Sand, 1974).

Observations made during 1973 using a continuous hydrometeor sampler (foil impactor) confirmed the observations presented above (May, 1974; Musil *et al.*, 1974). Although there is a question concerning distinguishing liquid from solid particles on the foil impactor, these observations are felt to be extremely useful when studying the microphysics of thunderstorm/hailstorms. Particle size distributions in the storms penetrated appear to be roughly exponential, or bi-exponential when large particles are present. Departures from the familiar Marshall-Palmer and Douglas distributions are apparent. It is also apparent that developmental work should continue on devices that can automatically count and size particles over the entire hail size spectrum and also distinguish liquid from solid particles, thereby providing much needed information on ice-water budgets of hailstorms.

Since the T-28 observations show that the strong inflow regions of hailstorms contain considerable amounts of supercooled water, as well as finding that these strong updrafts are often located far ahead of the high reflectivity zones, a strong case for effective hail suppression methods can be made (Sand et al., 1974c). Hailstones rely on supercooled water for their continued growth; therefore the seeding material should be placed in these areas. This would allow the best chance for effectiveness of the seeding material because, presumably, the water could freeze prior to its being used in the storm's hail factory. In addition, seeding far away from the high reflectivity zones would allow a better chance for diffusion of the seeding material and therefore affect a larger portion of the cloud.

5. PERSONNEL CHANGES

No new staff members were hired for the project during the contract period. Mr. Garth Peterson left the regular employ of the Institute on 30 June 1974, although he continued as a mathematician-programmer through July and August on an hourly basis.

Work on the project supported by contract funds is listed by individuals in Appendix A. Due to the restricted funding, a number of other people normally assigned to the T-28 project were reassigned to other Institute projects or took leaves of absence to work elsewhere.

ACKNOWLEDGMENT

The information upon which this report is based was obtained during the National Hail Research Experiment activities organized by the University Corporation for Atmospheric Research and sponsored by the National Science Foundation (Prime Contract Number NSF-C460, Subcontract Number NCAR 182-71).

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APPENDIX A

List of Personnel Associated with NHRE Project
1 May 1974 - 28 February 1975

Name	Title	Months Worked Under Referenced Contract
Professional		
Arnett S. Dennis	Director (1 July 1974-Present)	1.25
Richard A. Schleusener	Director (28 February 1974-30 June 1974)	.20
Jerry L. Halvorson	Junior Research Engineer	3.86
John H. Hirsch	Research Meteorologist	.10
Gary N. Johnson	Acting Head, Engineering Group	3.59
Dennis J. Musil	Research Meteorologist	5.60
Garth Peterson	Mathematician-Programmer	.35
Wayne R. Sand	Pilot-Meteorologist	9.65
Paul L. Smith, Jr.	Head, Engineering Group	.05
		24.65
Technical Staff		
Rudolph D. Flohr	Electronic Technician	5.35
Jon E. Leigh	Aircraft Mechanic	13.39
		18.74
Graduate Students		
Edwin L. May		3.00
William S. Shaw		3.00
John F. Spahn		2.00
Steven F. Weber		2.00
		10.00

APPENDIX A (Continued)

Name	Title	Months Worked Under Referenced Contract
Undergraduate Students		
Trond B. Pedersen		4.40
Steven F. Weber		.91
		5.31
Secretaries		
Sheryl K. Hunter		.90
Joie L. Robinson		1.59
Carol Vande Bossche		.50
Ramona M. Young		.10
		3.09
Total Man-months		59.24