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FINAL REPORT OF T-28 ARMORED AIRCRAFT DURING THE PERIOD 1 MAY 1972 - 1 MAY 1973

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ABSTRACT

A North American T-28 aircraft has been developed as a research tool to investigate the inside of active, mature thunderstorms. The aircraft has completed a full summer of successful operations consisting of 83 penetrations of active thunderstorms.

The basic aircraft and the instrumentation package have proven to be functional in this environment. Based on the first successful summer of operations, a number of improvements in the system were developed and a number of additional sensors were added.

Computer programs to reduce the data have been developed and T-28 data in numerous forms are now available.

The data taken during the 1972 season provided substance for a number of scientific papers and reports.

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1. INTRODUCTION

This report covers the period 1 May 1972 to 1 May 1973. The 1972 field season operations are discussed. Changes in the aircraft and the problems prompting these changes are described. Data system additions and changes are discussed in some detail along with the scheme for data reduction and analyses.

A list of papers and reports written during this contract period is included as Appendix A. A breakdown of man-months expended on the project is included as Appendix B.

2. OBJECTIVES

The overall objective of the research is to use the armored T-28 to obtain data within and in the immediate vicinity of hailstorms. The specific ojectives include:

1. Obtaining measurements of updrafts in regions of hail formation and growth;

2. Determining the composition of high radar reflectivity zones;

3. Studying ice-water budgets in hailstorms;

4. Comparison of data gathered by the T-28 and output from numerical models of hailstone and hailstorm growth being developed under other sponsorship;

5. Providing a measurement platform for the devices designed by Dr. Tom Kyle of NHRE; specifically total liquid water content (Kyle evaporator) and drop-size distributions (Kyle spectrometer); and

6. Use of the T-28 as a platform for other special measurements, such as the Langer ice nuclei device.

Objectives 4, 5, and 6 were added after the 1972 field season.

3. THE AIRCRAFT

3.1 Development of T-28 Concept and System

The concept of using an aircraft to penetrate thunderstorms in an attempt to gather scientific data has a long history, probably originating in 1949 with the thunderstorm project (Byers, 1949). The idea of developing a special aircraft to penetrate thunderstorms, gather essential data and not be concerned with hail damage began to take shape at the Institute of Atmospheric Sciences in 1966 with the award of a National Science Foundation grant to begin work on developing such an aircraft. A North American T-28 (N510MH) aircraft (Fig. 1) was acquired and armor-plated for hailstorm penetration by a commercial firm under previous grants to the South Dakota School of Mines and Technology from the National Science Foundation. The design is such that the aircraft has a reasonable chance of surviving substantial hail encounters. This is not to say that three inch hail would not damage the aircraft but that it should still be flyable after such an encounter. This work is reported upon by Williamson and MacCready, 1968; Williamson, 1969; and MacCready and Williamson, 1970.

The 1970 and 1971 field seasons produced a total of five thunderstorm penetrations. This period represented one of development of the concept and severe aircraft mechanical problems. As a result of many mechanical problems the aircraft was completely overhauled and the engine replaced prior to the 1972 season. This further work and development of the T-28 is reported by Sand _et al._, 1972a and Sand _et al._, 1972b. The year 1972 represented the first real productive season with the aircraft compiling 83 penetrations of active thunderstorms.

3.2 Aircraft Problems and Changes

Considerable work was done on the aircraft during this contract period as could be expected for an aircraft used in this manner. The prop deicing boots were replaced twice due to separation from the aircraft or damage during hail encounters. The cooling fins on the cylinders are the most severe continuing problem. Every time hail is encountered these fragile fins are bent. They are easy to repair but require continued maintenance.

Three engine cylinders required replacement during the 1972 field season due to low compression. This put the aircraft down for two weeks and represented the only down time during the season.

A number of other minor mechanical problems were encountered, none of which required more than a few hours to repair.

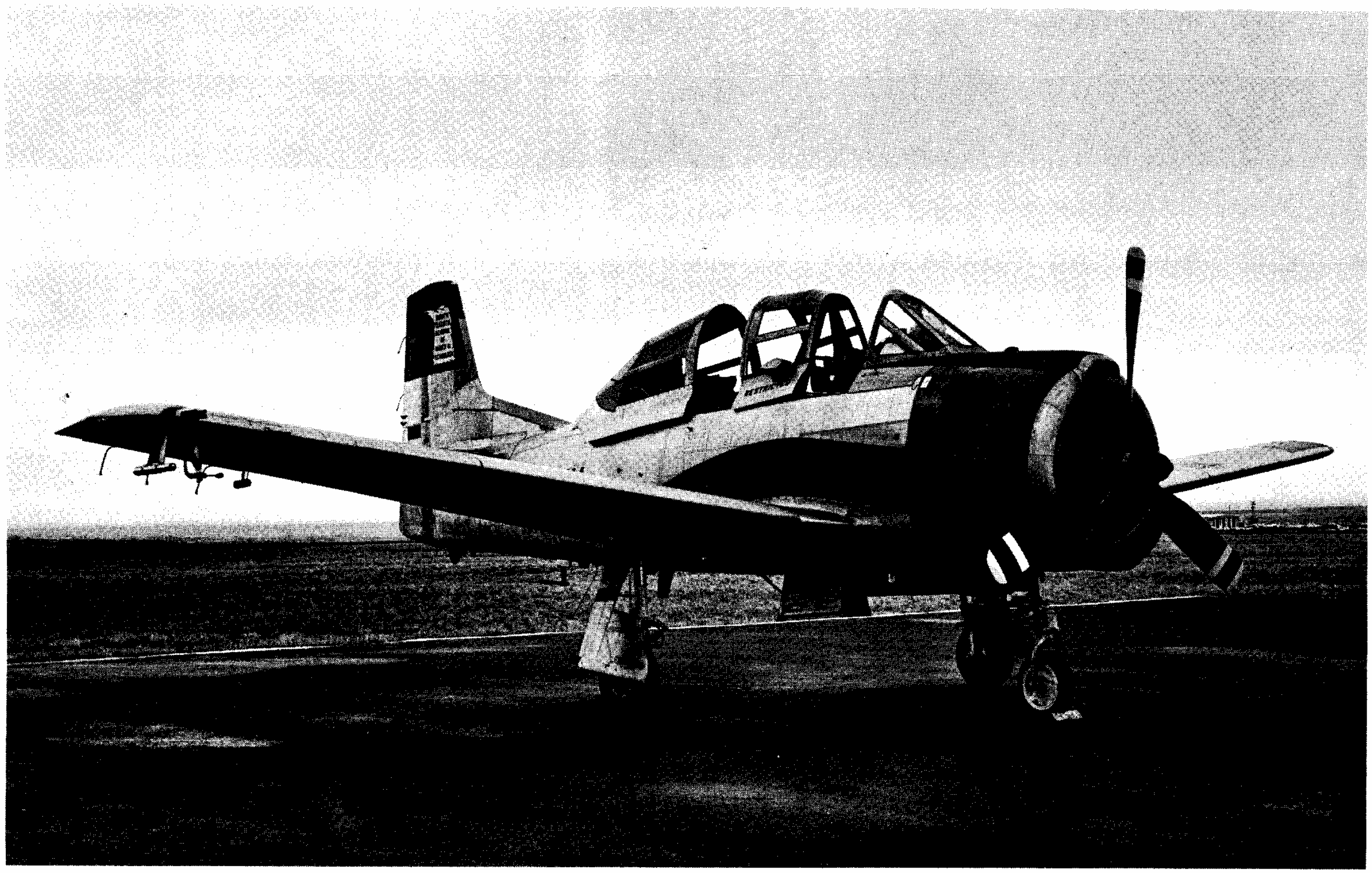

Fig. 1. Armored T-28 used for thunderstorm penetration.

To alleviate the possibility of extensive down time for major parts during the 1973 field season, it was decided to gather an inventory of those parts most frequently prone to failure. This has been accomplished and includes such things as: carburetor, generator, starter, voltage regulator, tires, wheels, fuel pump, vacuum pump and engine cylinders.

A passive ice depth probe was manufactured and added to the aircraft during the 1972 season. This device is pictured in Fig. 2. It is merely a small airfoil attached to the side of the canopy within easy view of the pilot. The airfoil has a probe protruding from its leading edge with calibration marks on it. This enables the pilot to accurately measure the ice thickness on the aircraft. This will also provide a ready comparison for the Rosemount icing rate probe discussed in Section 4.

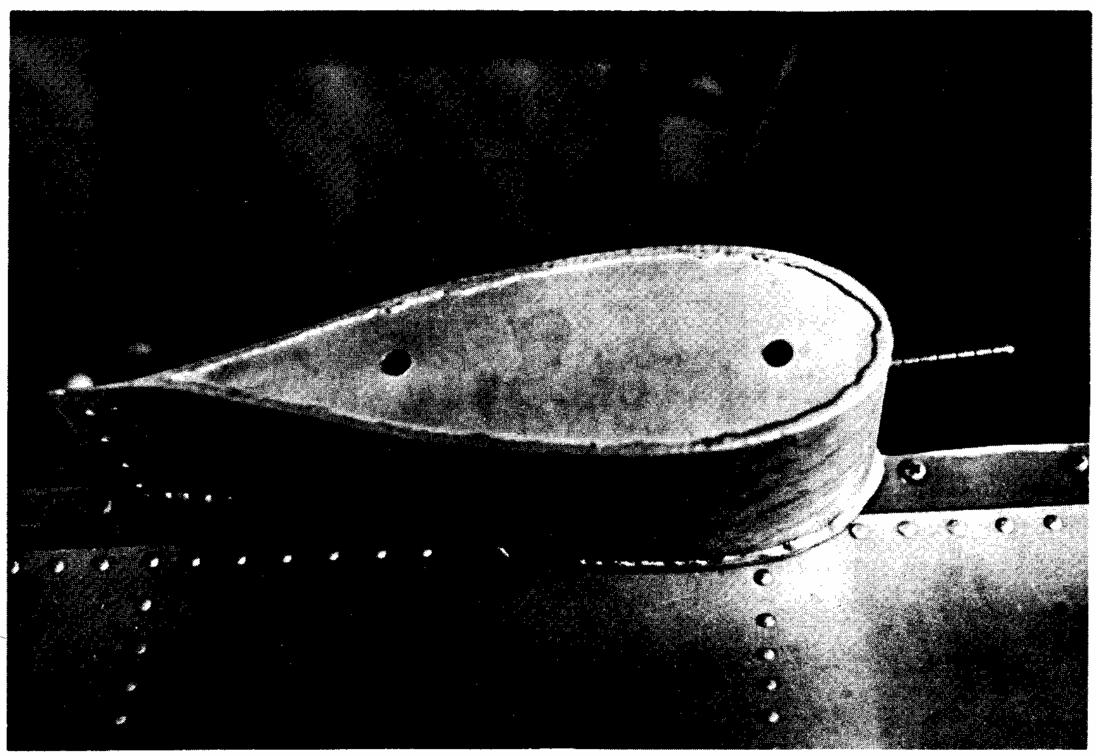

Fig. 2. Passive ice depth probe.

Lightning spikes (Fig. 3) were added prior to the 1973 season. The addition of these devices to all the tips was prompted by frequent lightning strikes during the 1972 season.

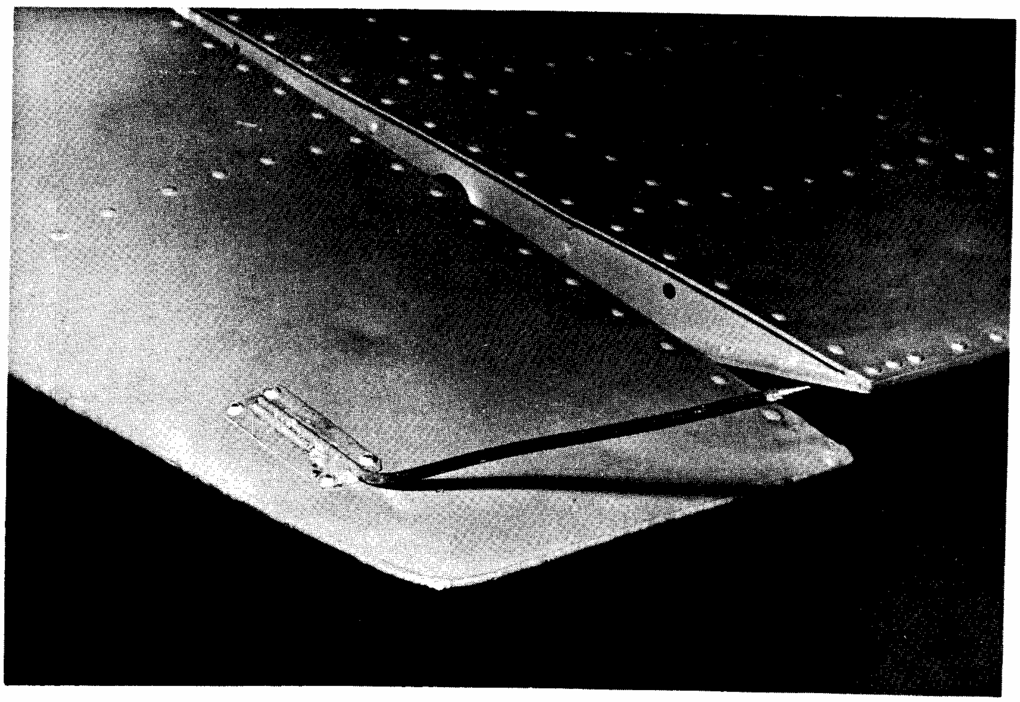

Fig. 3. Lightning spikes as on all T-28 extremities.

4. INSTRUMENTATION

Table 1 represents a summary of the instrumentation carried during the 1972 field season and a subjective data quality statement for each component of the data system.

Table 2 represents the planned data system components and data channel assignments for the 1973 field season. The additions (over Table 1) listed in this table were all made to enhance the ability of the T-28 system to achieve the objectives listed in Section 2. The additions and changes in the data system are described below.

4.1 Laser Hail Sensor

The laser hail sensor is an instrument planned to enable in-flight acquisition of hailstone quantities and sizes. The device is designed to count hailstones and size them as they pass through a sheet of laser light about 1/3 m^2 in area. One millimeter diameter resolution will be possible. The laser hail sensor is an in-house design at the South Dakota School of Mines and Technology.

4.2 Rosemount Icing Rate

A Rosemount icing rate probe (Fig. 4) was added to the system to permit a quantitative measurement of the icing rate in the region of hail formation and hail growth. This could give a better understanding of the availability of supercooled water for hailstone growth.

4.3 Foil Impactor

A foil impactor (Fig. 5) will be added to permit acquisition of the ice and rain particle concentration in the size range from 250 μm to 1 cm.

4.4 Barnes PRT-5

A Barnes PRT-5 infrared temperature sensor will be furnished by NHRE for use on the T-28. This device will have a 5-7 μm filter and will sense the temperature of cloud particles within a few meters of the aperture.

4.5 Four-Channel Voice/Data Recorder

A Hewlett-Packard four-channel data and voice recorder will be added to the T-28 system. The four channels will be used to record (1) pilot's comments, (2) hailstone windshield impact noise,

TABLE 1

1972 T-28 Data - Quality Summary

Channel	Parameter	Quality
1, 2	Time	Always good, synchronized daily with Grover.
3	Ball Altimeter	Generally good. Within 1 - 5 mb.
4	Indicated Airspeed	Very good.
5	VOR	Unusable.
6	WSI Altimeter	Generally good. Within 1 - 5 mb.
7	DME	Very good, but broke lock frequently.
8	Manifold Pressure	Very good.
9	Rosemount Temperature	Unusable.
10	WSI Temperature	Good to within 1.5°C.
11	J. W. Liquid Water Content	Questionable. Flight and ground checks okay but numbers appear too low in cloud, 0.1 - 0.6 gm/m^3.
12	Rate-of-climb	Good, except in region of ±300 fpm it sticks at -300 fpm. Corrected for manifold pressure and airspeed to provide updraft information.
13	Regulated 5 Volts	Very good.
14	Accelerometer	Equipment never acquired.
15, 16	Kyle Evaporator	Generally good. Iced up frequently.
17	Spare	Unused.
18	Voice	Unused.
19	Event Code	Very good.
20	Spare	Unused.
21 - 24	Rain Rate 40	Unacceptable.
25 - 28	Joss Hail Sensor	Unacceptable. Threshold too high. Icing problem.
29	Spare	Unused.
—	Kyle Spectrometer	Unusable.
—	Voice Data	Poor, usable, low quality recorder.
—	Hail Noise	Poor, usable, low quality recorder.

TABLE 2

Planned Data System - Components for 1973

Channel	Parameter
1, 2	Time
3	Ball Altimeter
4	Indicated Airspeed
5	*VOR
6	*Rosemount Ice Rate
7	DME
8	Manifold Pressure
9	*Rosemount Temperature
10	WSI Temperature
11	J. W. Liquid Water Content
12	Rate-of-climb
13	Regulated 5 Volts
14	*Barnes PRT-5 Temperature
15	*Kyle Lyman Alfa Humidity, Total Water
16	Kyle Vp, Total Water
17	Event Code
18	*+ Acceleration (+G)
19	*- Acceleration (-G)
20	Spare
21 - 24	*Rain Rate 40
25 - 33	*Hail Sensor
36 - 49	Spare
—	Kyle Spectrometer
—	*Voice Data, Hail Noise, Radio Communications and Redundant Data (4 Channel Recorder)
—	*Precipitation Sampler
—	*Foil Impactor
—	*Hail Camera
—	*Cloud Camera

*Equipment added or major repair prior to 1973 field season.

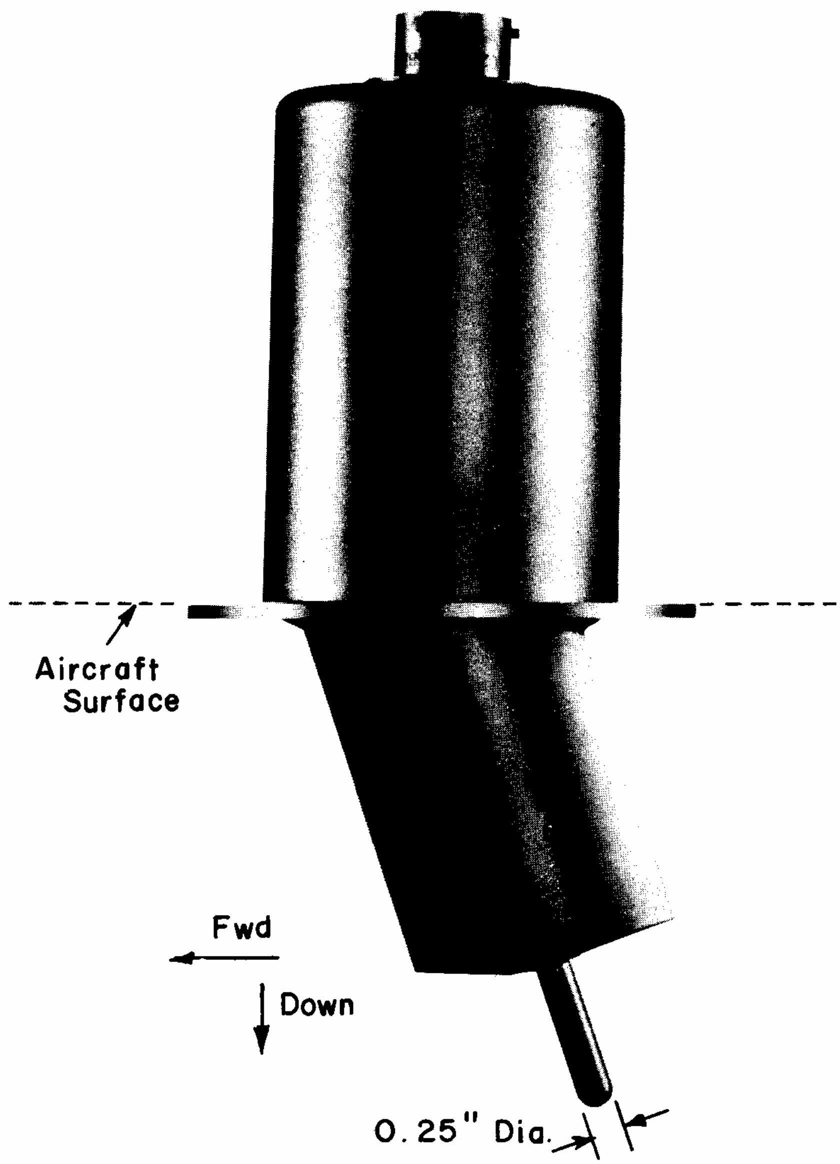

Fig. 4. Rosemount icing rate probe.

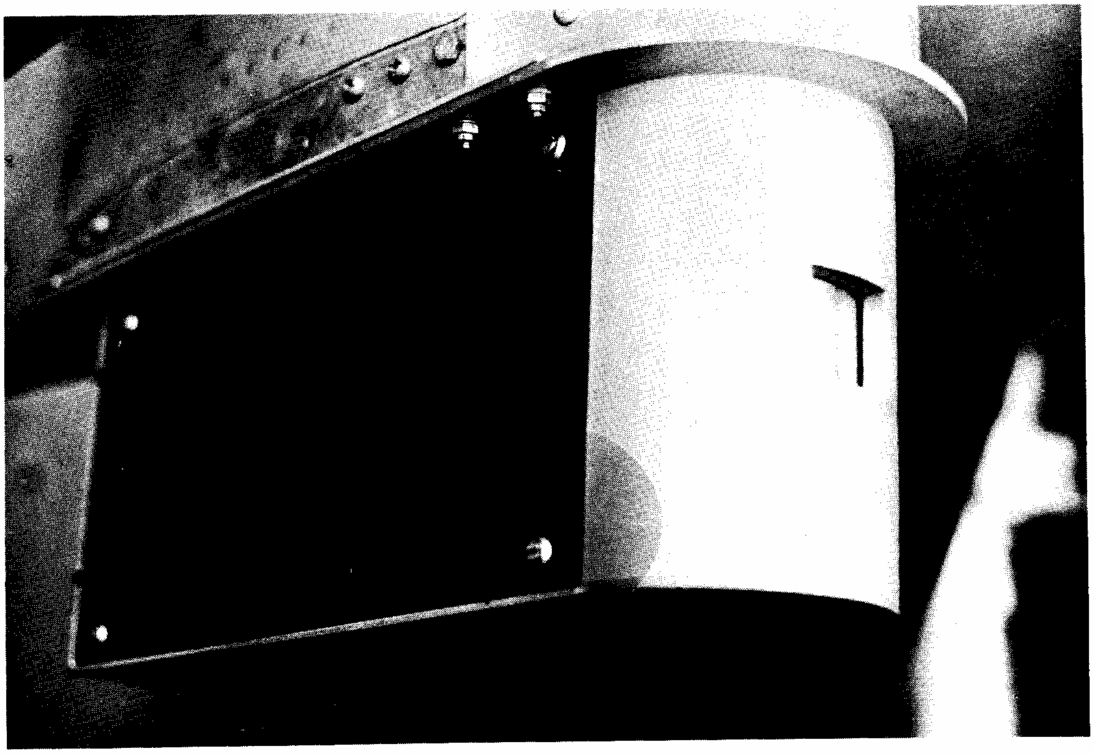

Fig. 5. Foil impactor.

(3) incoming radio transmissions, and (4) redundant data. The redundant data channel will duplicate the data tape from the DL-620 data recorder and permit transmission of the data via telephone link directly to the computer at Rapid City for a quick check on data quality.

4.6 Hail Camera

A camera hail detector is being developed by NHRE personnel for use on the T-28. This camera will photographically record the presence and quantity of small hailstones.

4.7 Cloud Camera

A general purpose super 8 mm cloud camera is planned as an addition to the T-28 system. This camera will have an automatic shutter and will be remotely controlled. It will be used to record the outward appearance of clouds being penetrated by the T-28.

4.8 Event Code

A refined event code system will be developed for use during the 1973 field season. The system will place an automatic event code on the data tape when certain portions of the system are activated thus relieving the pilot of this chore and placing a record in the permanent data of these special events (i.e., in cloud, cloud camera on, hail camera on, and Langer AgI nuclei detector on).

4.9 Precipitation Sampler

A device to capture precipitation samples inside an active thunderstorm will be designed and built by NCAR for addition to the T-28 system (Fig. 6). This device will have the capability of taking three separate samples. About 2.4 cubic meters of air will be sampled during each event.

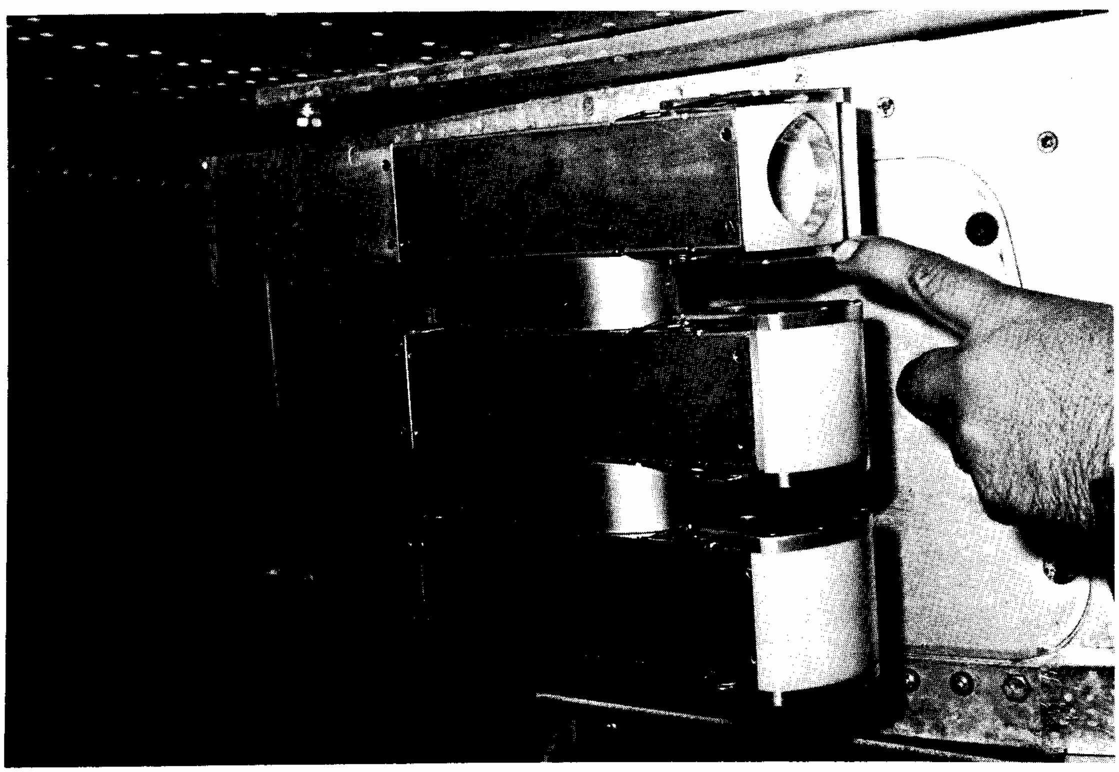

Fig. 6. Precipitation sampler.

5. FIELD OPERATIONS

The T-28 was based at Cheyenne, Wyoming for the 1972 field operations. Cheyenne was chosen for a base of operations because of its proximity to the NHRE special use airspace and because of the outstanding airport facilities available there.

The objective of the maintenance crew in Cheyenne was to keep the aircraft in a ready status whenever there was a possibility of thunderstorms in the NHRE operations area. When the NHRE operations staff at Grover reached a decision to declare a research day, a call was placed to the crew at Cheyenne instructing them where the potential test case was located and when to launch the T-28.

A flight plan was kept on file with the Cheyenne tower and with Denver Center so the T-28 could obtain an IFR clearance to the operations area in a very short time. Once the T-28 was in the special use airspace it was controlled by specially designated FAA personnel in addition to the project meteorologist for the T-28 project, who was located at Grover.

Vectors were prepared by the project meteorologist and given to the T-28 so that it could penetrate the highest reflectivity areas of the cloud and yet only penetrate clouds where the reflectivity was less than 55 dBz. According to Chisholm (1968) and Dennis et al. (1971), a 50 dBz reflectivity aloft represents a threshold reflectivity for hail at the ground. Therefore, the 55 dBz value represents a strong possibility of encountering hail of moderate but not excessive size in the cloud. This procedure, in fact, led to 15 hail encounters during the 63 penetrations used for analysis. The largest hail was approximately 3/4 inch in diameter.

Penetrations were normally started at 22,000 ft MSL and consecutive penetrations were made at 2000 ft intervals down to 16,000 ft MSL. This routine was interrupted if the reflectivity rose above 55 dBz or if the aircraft acquired so much structural ice that the pilot felt it should be melted off the aircraft prior to another penetration attempt.

A normal research flight consisted of from one to seven penetrations. Normally about six penetrations were made prior to the time the T-28 became low on fuel and was forced to return to Cheyenne. A total of 83 penetrations were made during the 86.4 hours of flight time expended during the period of this report. A complete summary of the 1972 field operations can be found in Sand et al. (1972c).

Table 3 represents a summary of the dates and times during which data were gathered during the 1972 field season.

TABLE 3

1972 T-28 Data Summary

Dates	Flight Number	Times Data Are Available	Penetrations
2 June	18	1514:25 - 1634:45	3
9 June	24	1713:08 - 1810:55	7
15 June	27	1634:10 - 1732:46	6
17 June	28	1554:47 - 1557:52	1
17 June	29	1725:34 - 1736:19	2
21 June	33	1730:26 - 1752:15	3
6 July	35	1641:14 - 1744:11	4
7 July	36	1806:42 - 1855:05	4
11 July	38	1636:19 - 1722:23	5
19 July	41	1628:58 - 1727:51	5
22 July	42	1603:32 - 1659:04	5
25 July	44	1547:33 - 1657:43	6
25 July	45	1852:47 - 1906:36	2
26 July	46	1704:37 - 1800:32	6
27 July	48	1508:39 - 1631:25	5
1 August	51	1758:09 - 1832:10	6

6. DATA REDUCTION AND ANALYSIS

The data reduction scheme was extensively developed during this period. Computer programs were written to reduce and display the data in a number of ways. Table 4 is a list of output parameters. This list will be expanded prior to the 1973 season with the addition of the instruments described in Section 4. The maximum, minimum, average, spread and standard deviation of each of these variables was computed for each penetration. The digital data were then plotted by the computer to give analog traces of all variables relative to time. The recorded pilot's comments during the penetrations were used to acquire other information such as the occurrence and relative size of hail encountered, turbulence, icing, and other general comments.

The flow of data from the aircraft platform to the final hard copy form is presented in Fig. 7.

A statistical study was begun to attempt to relate the occurrence of hail to severe turbulence, updraft maximum, and liquid water content. This study is still in progress and will be covered in a future report.

Relating the aircraft data to the radar data to determine the composition of the high radar reflectivity zones has been one of the chief objectives of the project. This study has been delayed due to the lack of radar data in a usable form. The IAS developed a computer program to obtain vertical sections through the radar data along the aircraft track. The vertical sections, plus NHRE 10-cm CAPPI displays, will permit a comparison with the aircraft data to determine the composition of the high radar reflectivity zones.

Considerable work has been done comparing the T-28 data to the output of numerical models. Some of this work is presented by Musil et al. (1973).

TABLE 4

T-28 Data Computer Output Parameters

Indicated Air Speed (knots)

Manifold Pressure (in. of hg.)

Rate-of-Climb (m/sec)

Ball Altimeter (ft MSL)

DME (nm)

WSI Air Temperature (C)

J. W. Liquid Water Content (g/m^3)

WSI Altitude (ft MSL)

Kyle Liquid Water Content (g/m^3)

Event Code

Cloud Temperature (C)

Virtual Temperature (C)

Buoyancy (C)

Updraft Velocity (m/sec)

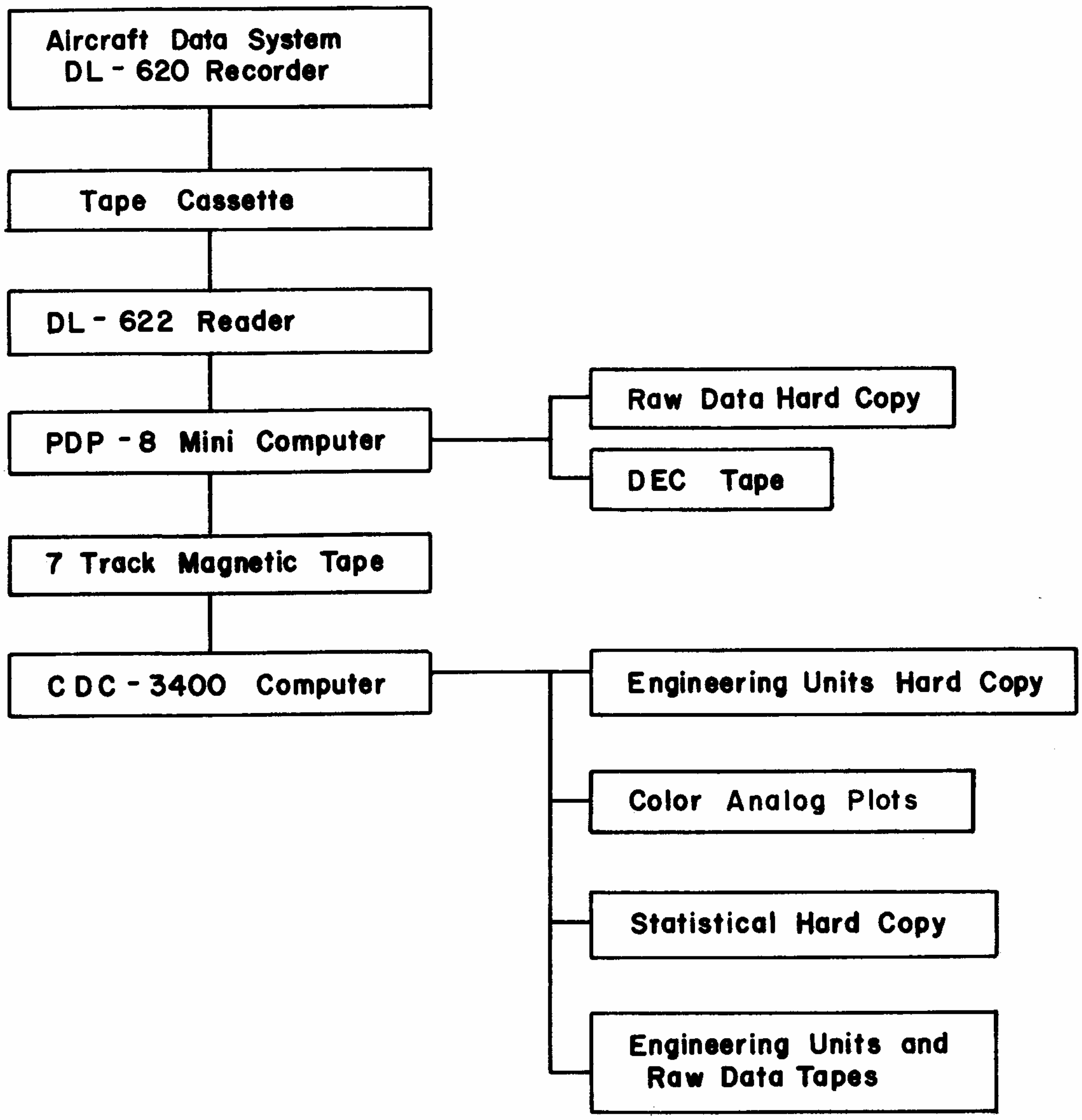

Fig. 7. T-28 data flow schematic.

7. PERSONNEL CHANGES

Mr. Jon Leigh was hired as aircraft mechanic effective 24 October 1972. Mr. Rudy Flohr was added to the full-time staff on the T-28 project as an electronic technician on 6 February 1973.

8. SUMMARY AND CONCLUSIONS

1. The T-28 was used successfully as a platform for obtaining meteorological information from hailstorms.

2. Data reduction and analysis procedures have been developed for analysis of the data collected.

3. Radar data are just starting to become available to compare with regions penetrated by the T-28 during 1972.

4. Numerous additions to the data system and refinements of it were accomplished prior to the 1973 field season.

ACKNOWLEDGMENT

The work described in this report was part of the National Hail Research Experiment and was supported by the National Science Foundation, Prime Contract Number NSF-C460 and under Subcontract Number NCAR 182-71.

Appreciation is expressed to Mr. Jon Leigh and Mr. Leonard Block for maintenance of the aircraft and to Mr. Kenneth "Chuck" Jasper and Mr. Rudolph "Rudy" Flohr for maintenance of the data system.

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Williamson, R. E., and P. B. MacCready, Jr., 1968: Aircraft probing of hailstorms. Final report by MRI to Institute of Atmospheric Sciences, South Dakota School of Mines and Technology, Rapid City, South Dakota. (MRI 68 FR-757), 37 pp.

________, 1969: Aircraft probing of hailstorms. Final report by MRI to Institute of Atmospheric Sciences, South Dakota School of Mines and Technology, Rapid City, South Dakota. (MRI 69 FR-841), 24 pp.

APPENDIX A

List of Publications

IAS Report 72-17	Final Report of T-28 Armored Aircraft During the Period 1 May 1971 - 1 May 1972. Sand, W. R., R. A. Schleusener, and D. J. Musil. Published October 1972. 55 pp.
IAS Report 72-18	T-28 Summary of Operations 1972 NHRE Field Season. Sand, W. R., D. J. Musil, and R. A. Schleusener. Published September 1972. 9 pp.
Science Article	Water Content in Convective Storm Clouds. Kyle, T. G., and W. R. Sand. Submitted to Science for publication.
WMA Article	Observed Updrafts and Hail Inside a Thunderstorm. Sand, W. R., D. J. Musil, and R. A. Schleusener. Submitted for publication in the Weather Modification Association Journal.
Severe Storms Conference Article	The Vertical Velocity Profile in Thunderstorm Updrafts. Kyle, T. G., and W. R. Sand. Submitted for presentation at the 8th Severe Local Storms Conference.
Severe Storms Conference Article	An Interior View of a Hailstorm Near 20,000 Ft. Musil, D. J., W. R. Sand, and R. A. Schleusener. Submitted for presentation at the 8th Severe Local Storms Conference.
JAM Article	Analysis of Data for T-28 Penetrating Aircraft. Musil, D. J., W. R. Sand, and R. A. Schleusener. Submitted for publication in J. Appl. Meteor.

APPENDIX B

List of Personnel Associated with NHRE Project

1 May 1972 - 30 April 1973

Name	Title	Months Worked Under Referenced Contract
Professional		
Richard A. Schleusener	Director	2.05
John Callahan	Junior Engineer	.46
Arnett S. Dennis	Head, Meteorologist Analysis Group	.05
John H. Hirsch	Research Meteorologist	1.69
Gary N. Johnson	Junior Research Engineer	5.19
Dennis J. Musil	Research Meteorologist	6.62
William G. Myers	Research Engineer	8.11
Garth Peterson	Mathematician Programmer	1.93
Wayne R. Sand	Pilot	11.34
Paul L. Smith	Head, Engineering Group	.27
		37.71
Technical Staff		
Leonard Block	Aircraft Mechanic	5.08
Rudolph D. Flohr	Electronics Technician	2.86
Jon Leigh	Aircraft Mechanic	6.07
		14.01
Graduate Student		
William S. Shaw		4.00
		4.00
Undergraduate Students		
Andrew Furiga		1.68
Jerry L. Halvorson		1.78
Kenneth E. Jasper		9.30
Ronald E. Klein		1.53
Edwin L. May		1.93
		16.22
Secretaries		
Karen Brown		.97
Joie Robinson		.85
Carol Vande Bossche		.18
Ramona M. Young		.19
		2.19
Total man-months		74.13