Report 72-4

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FINAL REPORT ON T-28 ARMORED AIRCRAFT DURING THE PERIOD 1 MAY 1970 - 1 MAY 1971

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ABSTRACT

A North American T-28 aircraft was developed as a research tool to investigate the inside of active mature thunderstorms.

The objectives of this project under NSF Grant-24651 were to: (1) put the aircraft into working order after an engine failure which necessitated the replacement of the engine and (2) develop the instrumentation package into a functional data-gathering system. It was also proposed to make some actual in-cloud measurements with the system to examine:

(1) The updraft structure in regions of hail formation.

(2) The composition of high radar reflectivity zones.

(3) The ice-water budgets of hail-producing regions.

The instrumentation on the T-28 and the aircraft itself were put into service during the summer of 1970, so that it could be used to gather data inside thunderstorms. The aircraft was operated for twelve days and flown on three research missions with the Joint Hail Research Project in Colorado and on one mission in the Rapid City area. Data from the Rapid City mission, which consisted of five penetrations of active thunderstorms, were analyzed. Results of this analysis are presented with some of the recorded and derived variables.

The limited data from five penetrations led to some tentative conclusions on the relationship of certain parameters to the occurrence of hail. The data derived from the T-28 penetrations suggest that the presence of hail is related to the following variables:

(1) Penetrations elapsed time. (Total time the aircraft is in cloud.)

(2) Altitude spread. (The difference between highest and lowest altitude of the T-28 on a given pass.)

(3) Standard deviation of the rate-of-climb.

(4) Maximum buoyancy.

(5) Mean buoyancy.

The data derived from the T-28 penetrations also suggest that the presence of hail during a penetration does not seem to be related to the following variables:

(1) Maximum liquid water content.

(2) Mean liquid water content.

(3) Maximum rate-of-climb.

(4) Mean rate-of-climb.

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1. INTRODUCTION

This report summarizes the work done under NSF Grant GA-24651 during the period 1 May 1970 to 1 May 1971. Man months expended on the project are summarized in Appendix A.

A North American T-28 aircraft 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 aircraft was delivered to the South Dakota School of Mines and Technology in January 1970.

The aircraft experienced an engine failure in February 1970. A replacement engine was purchased under NSF Grant GA-11749. Prior to the 1970 field season it was discovered that the T-28 needed a wing spar cap modification. This work was accomplished at the Naval Air Rework Facility, Pensacola, Florida.

Additional modifications to the meteorological instrumentation were accomplished during the spring and early summer of 1970 prior to use of the aircraft as a meteorological research platform during July and August 1970.

The aircraft was sent into the field in July 1970 to work with the Joint Hail Research Experiment in Colorado as reported by Schleusener et al., 1970. Three data-gathering missions were flown in Colorado and one mission was flown in the Rapid City area.

The objectives of the data-gathering missions were to:

(1) Determine the updraft structure in regions of hail formation.

(2) Determine the composition of high radar reflectivity zones.

(3) Determine ice-water budgets of hail-producing regions.

The non-availability of instrumentation precluded attempting objective (3) during the 1970 season.

The missions proved to be a means of gaining operational experience and establishing future requirements for the T-28 system. The missions also provided a better definition of radar support requirements.

The data recording and analysis scheme is described. A sample of the data gathered in the Rapid City area is presented in this report with a discussion of the results. The Rapid City data were chosen for analysis because of the availability of good supporting radar data. These data permit a preliminary analysis of the relationship of the various parameters measured by the T-28 and the presence of hail during a given penetration.

At the conclusion of the 1970 operational season the T-28 was grounded because of internal problems with the engine. This engine was overhauled during the winter months prior to the start of the 1971 season but failed prior to the 1971 season.

A discussion of future plans for the T-28 penetration aircraft is included in this report. These plans are based on lessons learned to date and include a major renovation program for the T-28. The data system will be expanded to enable achievement of the stated objectives.

2. THE AIRCRAFT

The T-28 is a modified North American T-28A (Fig. 1). The aircraft was modified to be used as a research tool for penetrating hailstorms and gathering data in an environment where heavy turbulence and hail are apt to be present.

The basic T-28A aircraft was modified with a larger engine to give it improved performance at high altitudes. The engine selected to replace the original R-1300 (800 hp) was the R-1820-87 (1250 hp). It was later determined that the R-1820-87 is not a strong enough engine to function properly on the modified T-28. It will be replaced with a newer, stronger, and more powerful R-1820-86A (1425 hp). This engine is identical to those currently used on operational military T-28 aircraft.

Basic modifications to the airframe were:

(1) The leading edges of the wings and tail were armor plated with 0.090 inch heat treated aluminum.

(2) The upper surface of the wings and tail were armor plated with an 0.032 inch heat treated aluminum.

(3) The leading edges of the engine cowling were armor plated with 0.125 inch aluminum.

(4) The canopy was replaced with a much stronger unit constructed of 0.125 and 0.090 inch aluminum and having side windows of 0.60 inch stretched acrylic. The windshield itself was replaced with flat sections of 0.75 inch stretched acrylic.

(5) Heavy aluminum grills were installed over the air intakes of the carburetor and oil cooler to restrict hail from entering these areas.

(6) The propeller governor and the push rod housings were armored to prevent hail damage.

(7) Propeller and carburetor alcohol anti-ice systems were installed.

(8) An instrumentation platform was installed in the baggage compartment area.

(9) Various meteorological sensors were installed on the wings of the aircraft.

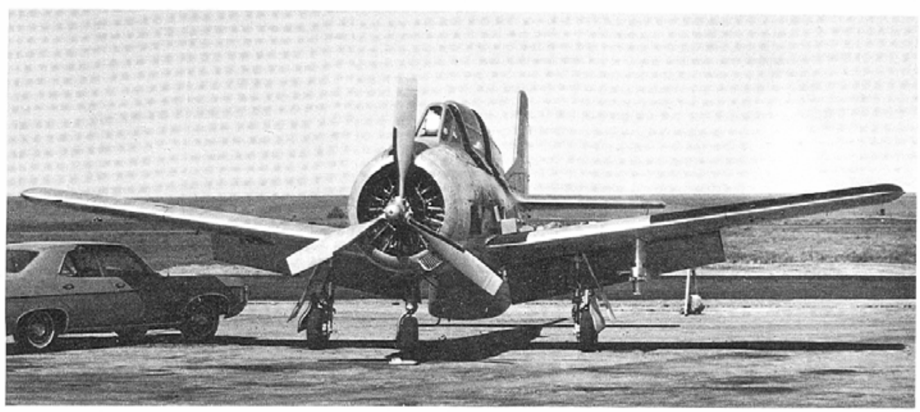

Fig. 1. Modified T-28 used for thunderstorm penetrations.

The following aircraft electronic equipment was installed:

(1) Three 360-channel communications radios.

(2) Three VOR receivers.

(3) An ILS with glide slope.

(4) A DME.

(5) An ADF.

(6) A transponder.

(7) Dual artificial horizons, one electric and one vacuum.

The initial airframe modifications on the aircraft were performed by a private contractor under a previous NSF Grant (Williamson and MacCready, 1968; Williamson, 1969; and MacCready and Williamson, 1970). Prior to the 1970 season it was discovered that a wing structural modification was required in accordance with U. S. Air Force Safety Time Complied Technical Order IT-28A-549/550/551. This modification consisted of the installation of spar caps which strengthened the wings to better withstand the turbulence in hailstorms. The work was accomplished under this grant in July 1970 by the Naval Air Rework Facility at Pensacola, Florida.

3. THE DATA SYSTEM

The data package on the T-28 includes sensors to measure various meteorological and aircraft parameters. The sensors are summarized in Table 1.

The recording system is a MetroData Systems Incorporated DL620A digital tape recorder which records 18 channels of data plus time. All channels can be recorded at a rate of 2.4 times per second. Normally, the maximum rate is used during storm penetrations, while outside the storms the channels are recorded once per minute.

With the exception of the sensors themselves, the entire data system was located in the baggage compartment of the airplane. It was only necessary for the pilot to change modes on the recorder prior to and after penetrations and put various event marks into the system to indicate significant observations.

A two-channel voice recorder was also carried as part of the instrument package. One channel was used to record the pilot's voice comments while the other channel was used to record hail impact noise from the windshield.

TABLE 1

Variables Recorded by the T-28 Instrumentation Package

PARAMETER	INSTRUMENT TYPE	MANUFACTURER	RANGE
Pressure Altitude	Pressure Transducer	Ball EX-210-B	-200 to 30,000 ft
Pressure Altitude	Pressure Transducer	CIC 7000	0 to 30,000 ft
Indicated Airspeed	Airspeed Transducer	CIC 7100	70 to 350 kts
Rate of Climb	Variometer	Ball 101A	-6000 to +6000 ft/min
*Vertical Acceleration	Accelerometer	Stratham A-45	± 15g
Temperature	Thermistor	WSI TS22	-30 to +30°C
*Temperature	Platinum Resistance	Rosemont 102AV2AP	-100 to +30°C
Liquid Water Content	Hot Wire	Johnson-Williams	0 to 6 gm/m^3
*Raindrop Spectrum	Impact Transducer	MetroData RR 40	0.35 to 7.25 mm
Position, Azimuth	VOR	NARCO MK 12A	0 to 360°
Position, Range	DME	NARCO UDI-4	0 to 100nm
Time	Crystal Controlled Oscillator	MetroData DL620A	hr, min, sec
Event Code	Voltage Level	IAS Fabricated	0 to 9 events

*Installed in the aircraft but not functioning properly during the 1970 project season.

4. DATA

4.1 Data Recording and Analysis

Data was recorded in the aircraft on the MetroData DL620A in digital format on a four-track one-quarter inch magnetic tape cartridge. To analyze the data the cartridge was played through a MetroData DL622 tape reader system into a PDP-8 computer where it was reduced to engineering units and could be printed out or written onto DEC tape for further analysis on the PDP-8. Computer programs were written to permit the display of certain parameters in analog form on a cathode ray tube for the period of a cloud penetration. Photographs could be taken of this display to give an analog pictorial representation of selected parameters during a given penetration.

Samples of the data printout and the computer generated analog displays of five penetrations are included as Figs. 2 through 6.

4.2 Definition of Variables

All the variables shown in Table 1 were recorded 2.4 times per second during penetrations. In addition a number of derived variables were considered in the analysis of data. The variables considered are defined as follows:

(1) Presence of hail. This event was manually recorded by the pilot with an event marker. A coded event mark was recorded on tape when hail was encountered and removed when there was no longer any hail. A verbal comment was also made on the voice recorder as to the relative size, hardness, and intensity of the hail. A capability exists, but was not functioning during these missions, whereby the sound of hail hitting the windshield can be recorded on a second channel of the voice recorder. The presence or absence of hail during a penetration is all that is considered in this report.

(2) Penetration elapsed time. The cloud entry and exit times were marked on the data tape by the pilot with an event code. Cloud penetration time is defined as the difference between these two times. Time is recorded to the nearest second from a crystal controlled oscillator.

(3) Altitude. Altitude was calculated from a measurement of atmospheric pressure. Atmospheric pressure is sensed with a pressure transducer. Output voltage

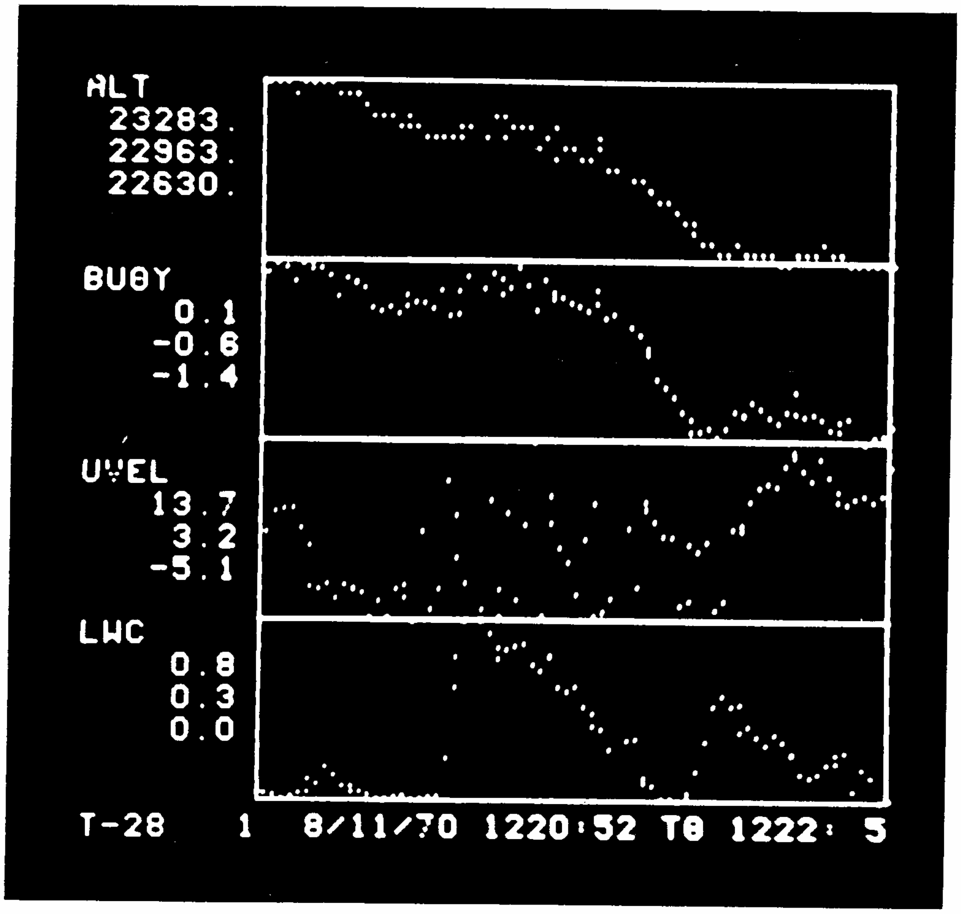

Fig. 2. Computer generated analog display of selected parameters during penetration number one, 1220:52 - 1222:05 MDT, 11 August 1970.

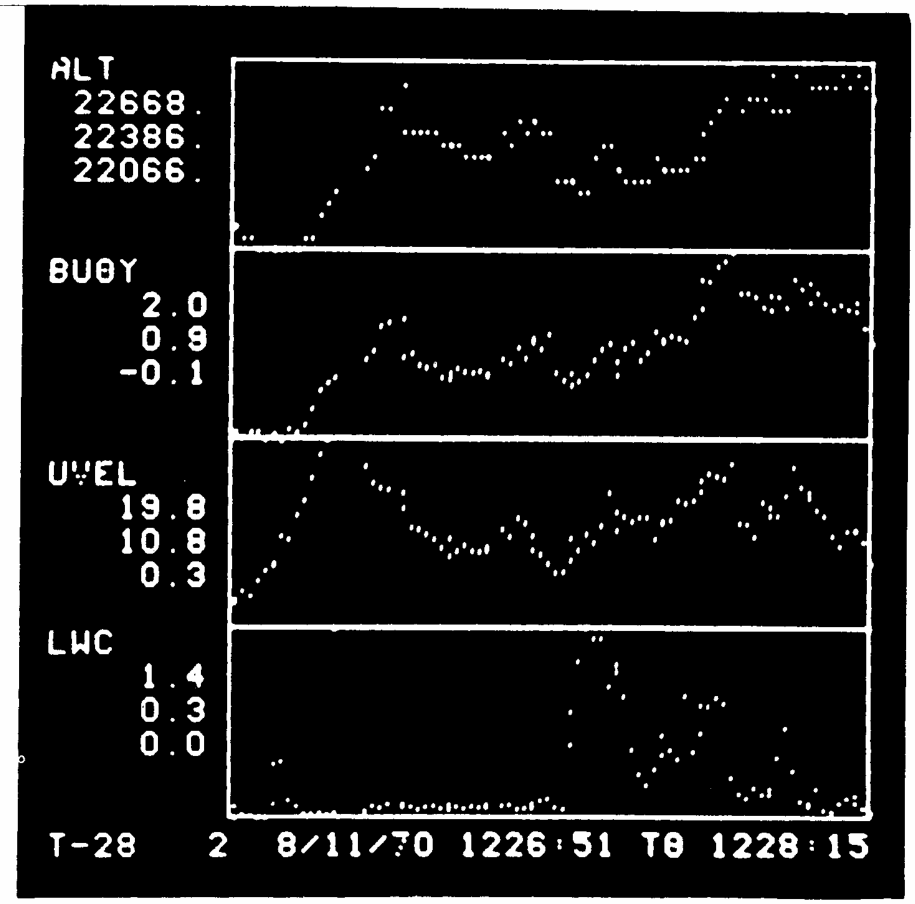

Fig. 3. Computer generated analog display of selected parameters during penetration number two, 1226:51 - 1228:15 MDT, 11 August 1970.

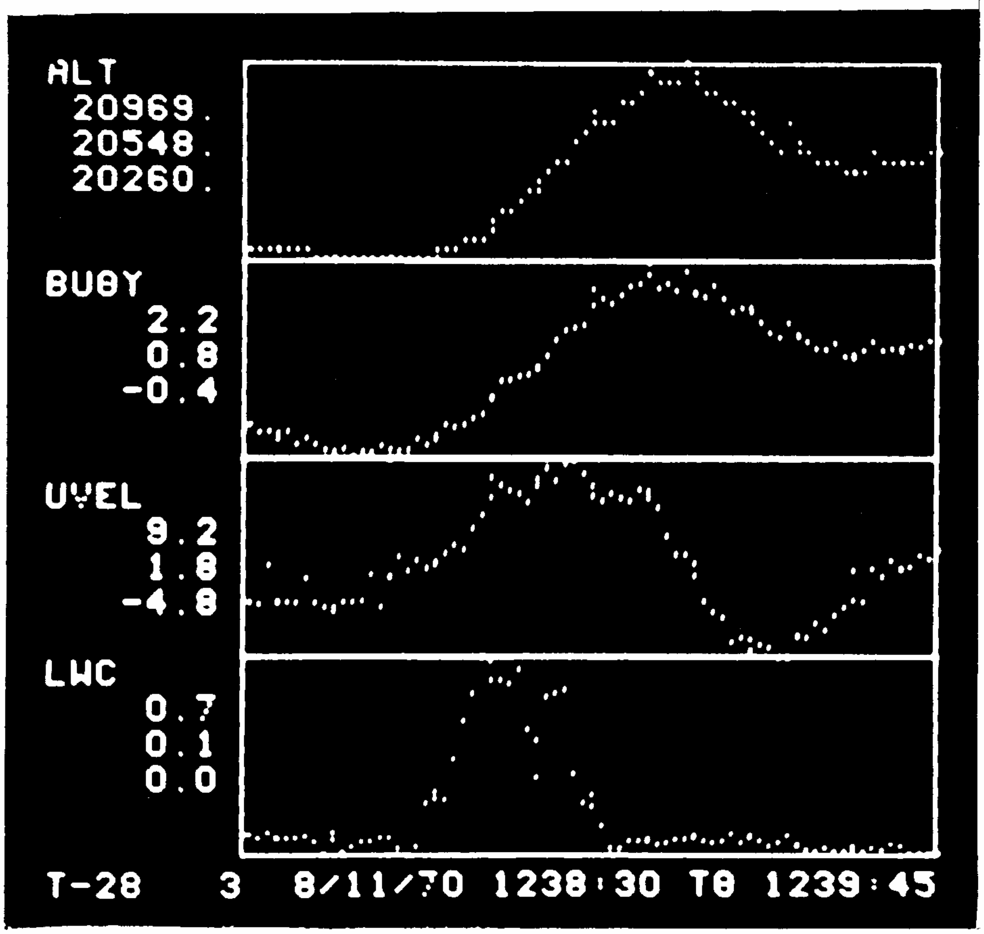

Fig. 4. Computer generated analog display of selected parameters during penetration number three, 1238:30 - 1239:45 MDT, 11 August 1970.

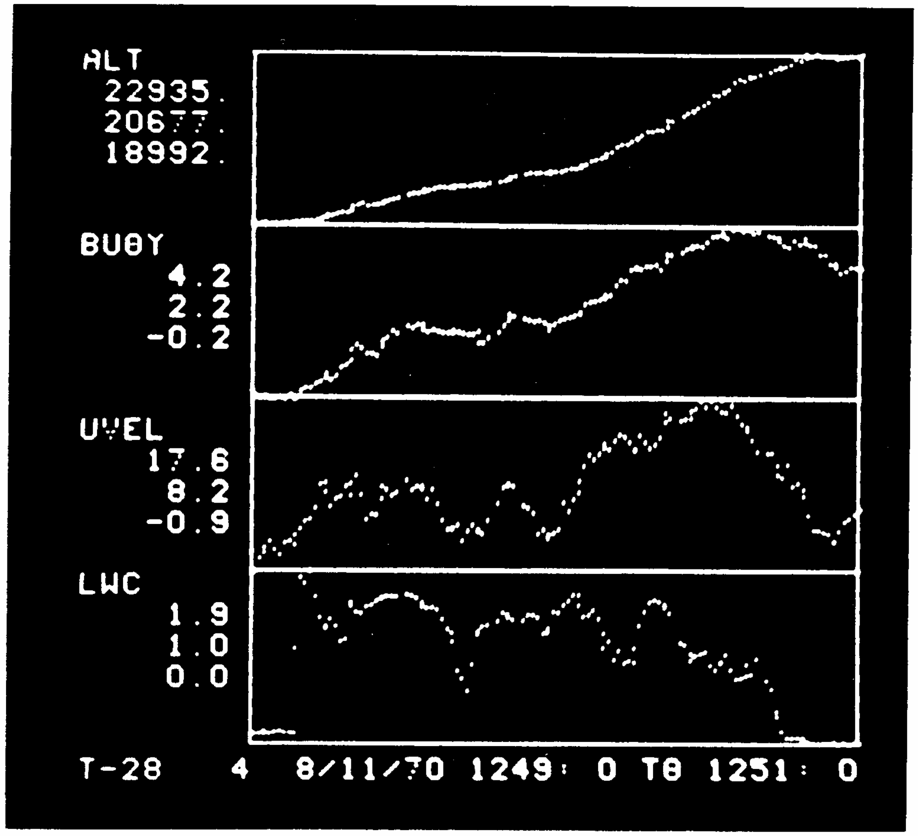

Fig. 5. Computer generated analog display of selected parameters during penetration number four, 1249:00 - 1251:00 MDT, 11 August 1970.

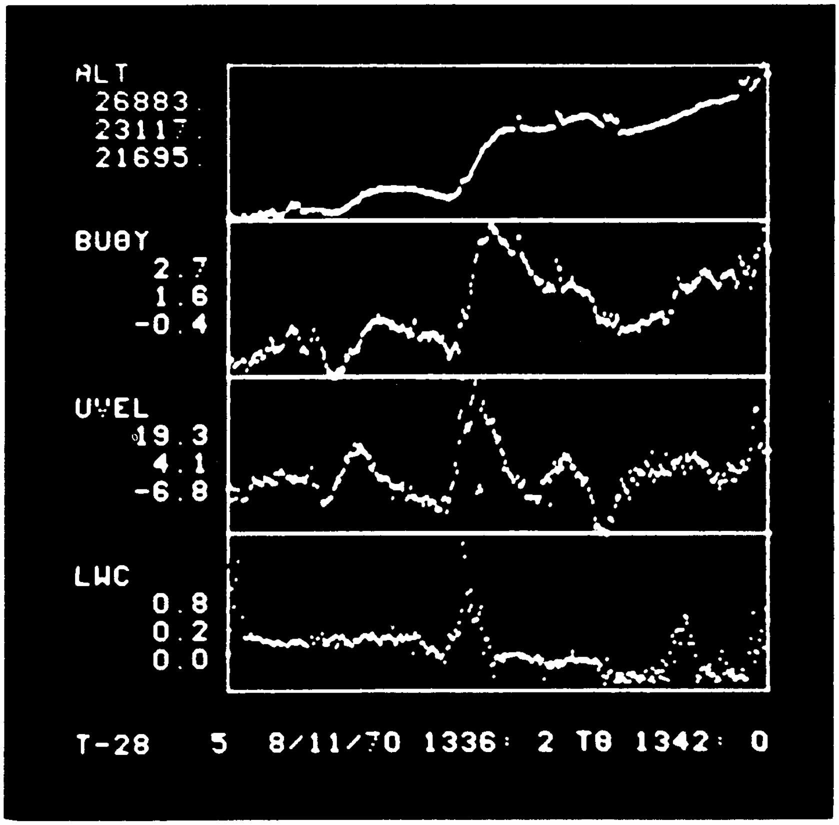

Fig. 6. Computer generated analog display of selected parameters during penetration number five, 1336:02 - 1342:00 MDT, 11 August 1970.

of the transducer system is linear throughout the range 10 to 30 inches of mercury, with an overall accuracy of ± 0.2 inches mercury. Pressure altitude is calculated from the above pressure, sea level altimeter setting, and a form of the hypsometric equation. Altitude spread is defined as the difference between the maximum and minimum altitude of the T-28 during a penetration.

(4) Temperature. Air temperature is sensed by a thermistor enclosed within a reverse flow housing. Output voltages are linear throughout the temperature range -30C to +30C with an overall accuracy of ± 0.2C. The measured temperature is corrected for dynamic heating by the computer program.

(5) Corrected temperature. Corrected temperature is defined as the temperature obtained by moist adiabatic lift or descent to the mean altitude of the flight through the cloud.

(6) Virtual temperature. Virtual temperature is calculated from the actual air temperature measured at a given altitude, delta Z and the saturation mixing ratio of the air to give the virtual temperature at the mean penetration altitude.

a. Delta Z. The height correction, delta Z, is the difference between the mean height of the cloud penetration and the actual height measured at any given time during the traverse through the cloud.

(7) Liquid water content. Liquid water content is sensed with a hot wire resistance sensor. Its range is from 0 to 6 gm m^{-3}.

(8) Rate-of-climb. Rate of climb is sensed by an electric variometer. Output voltages are linear throughout the range -6000 to +6000 ft min^{-1}. Voltages are converted by the computer program to m sec^{-1} for analysis.

(9) Buoyancy. Buoyancy is the virtual temperature difference between the virtual temperature in-cloud and the out-of-cloud virtual temperature. The difference is computed for each observation during the penetration and is defined as zero at cloud entry. This virtual temperature excess is an indication of buoyancy.

The pertinent equations used to determine the above variables are given in Appendix B.

4.3 Supporting Observations

An atmospheric sounding taken near the operating area, appropriate surface, and 500-mb charts give an overall picture of the general weather pattern during the cloud penetrations on 11 August 1970.

Radar data provide information on the maximum reflectivity, radar tops, and the general radar reflectivity structure of the storm.

Photographs of the cloud from the ground or from an aircraft at the time of penetration are also helpful in establishing an overall picture of the cloud system of interest.

5. A SAMPLE OF DATA FROM 11 AUGUST 1970

5.1 General Weather Situation

The general weather pattern is depicted in Figs. 7 and 8 by the 1200Z, 11 August 1970 surface and 500-mb charts. The Rapid City sounding for 1200Z is included as Fig. 9. The local forecast for the day called for thunderstorms in the area with a possibility of one-half inch hail aloft and one-quarter inch hail at the surface.

5.2 Data Available from Five Penetrations

Five penetrations of hailstorms were made in the Rapid City area on 11 August 1970. These data were chosen for analysis because of the available radar data and the relatively complete data output from the aircraft system. The sample provides a good representation of: (1) the aircraft's data-gathering capability, and (2) the data reduction scheme. The sample also permits an attempt to identify the parameters which are related to the presence of hail.

Nine different parameters were considered in the computer analysis of the data. Each pass was analyzed with the computer to determine the maximum, minimum, average, and standard deviation for each of the variables. This procedure was carried out for each of the five penetrations and significant results are summarized in Table 2. (Definitions of the various parameters are given in Section 4.)

It is recognized that five cloud penetrations do not represent a significant sample from which to draw scientific conclusions; however, it is possible to make certain observations by relating the parameters given in Table 2 to the presence of hail.

5.3 Supporting Radar Data

The Nike-Ajax radar PPI film showed a number of radar echoes in the Rapid City area during the afternoon hours. The clouds in which penetrations were made exhibited radar tops between 30-46K ft MSL with maximum equivalent radar reflectivities between 50-61 dBz. The penetrations were made between 1220 and 1342 MDT. Radar scope photography indicated that the storm continued to grow and remained a large well developed cell until 1445 MDT when dissipation was noted.

Some of the clouds in the area were seeded and have been discussed by Koscielski _et al._ (1971). Koscielski states that at the beginning of their test case (1130 MDT) the storm was inefficient but developed into a very efficient storm by 1230 MDT.

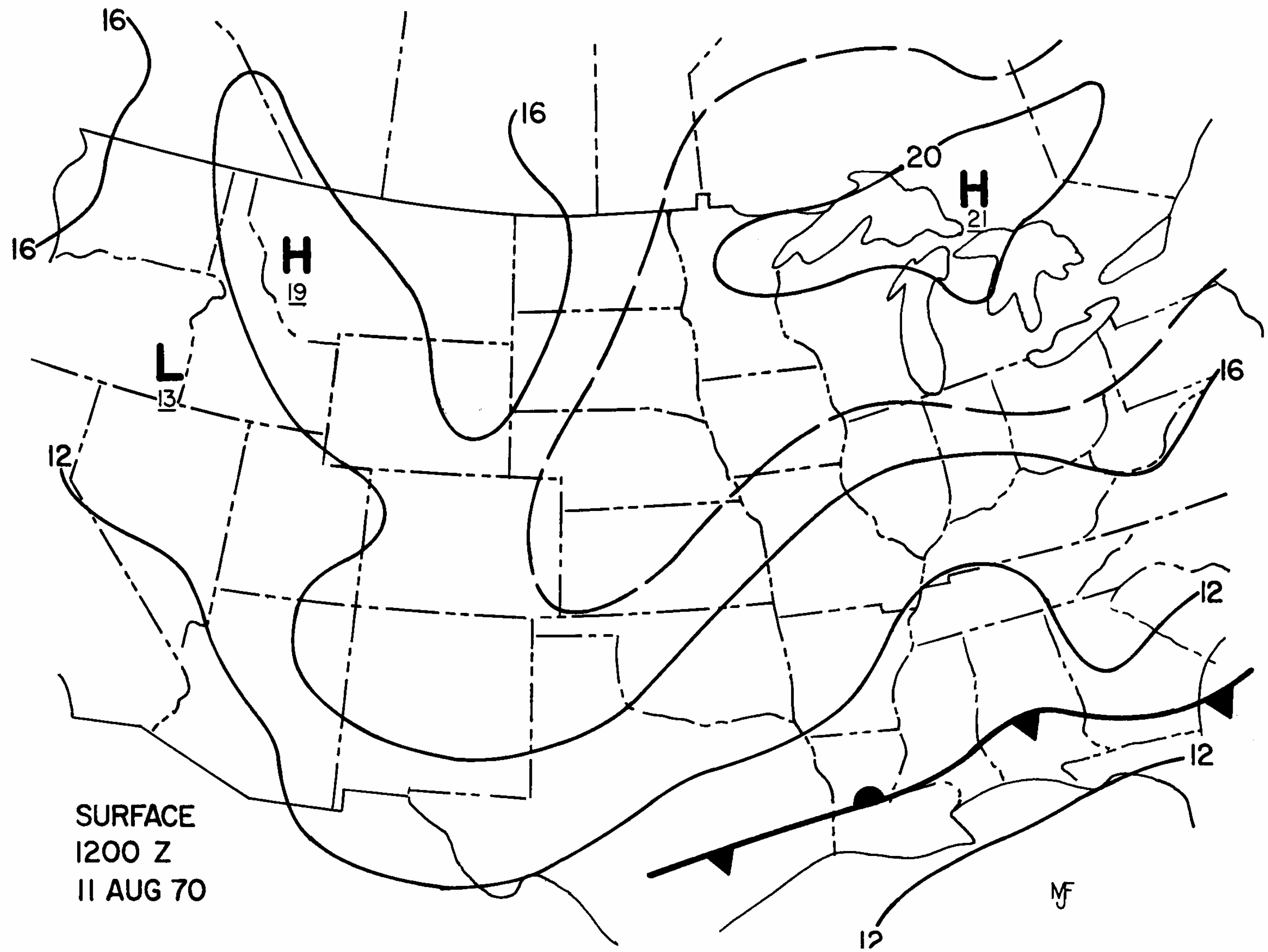

Fig. 7. Surface weather map, 1200Z, 11 August 1970.

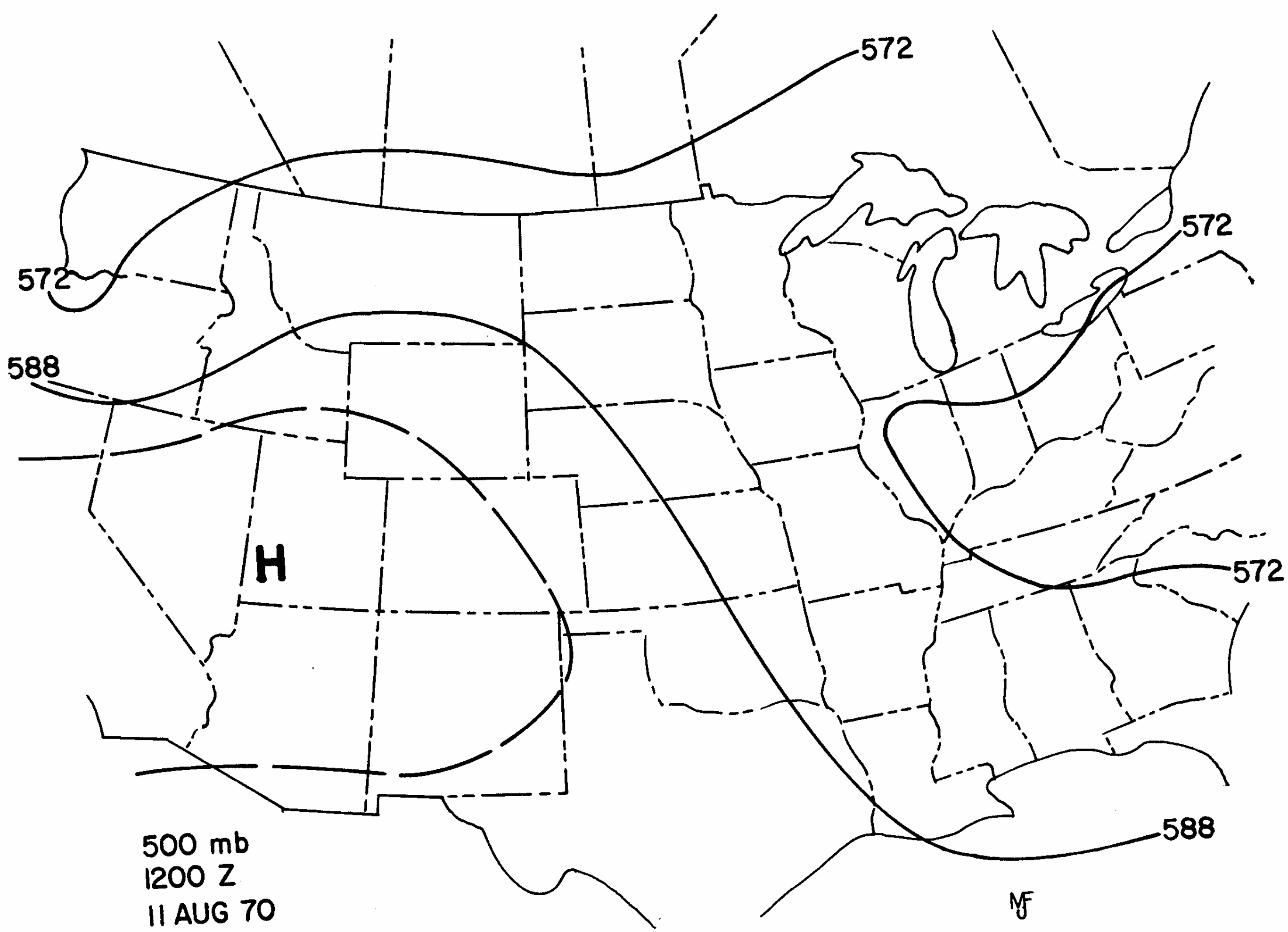

Fig. 8. 500-mb map, 1200Z, 11 August 1970.

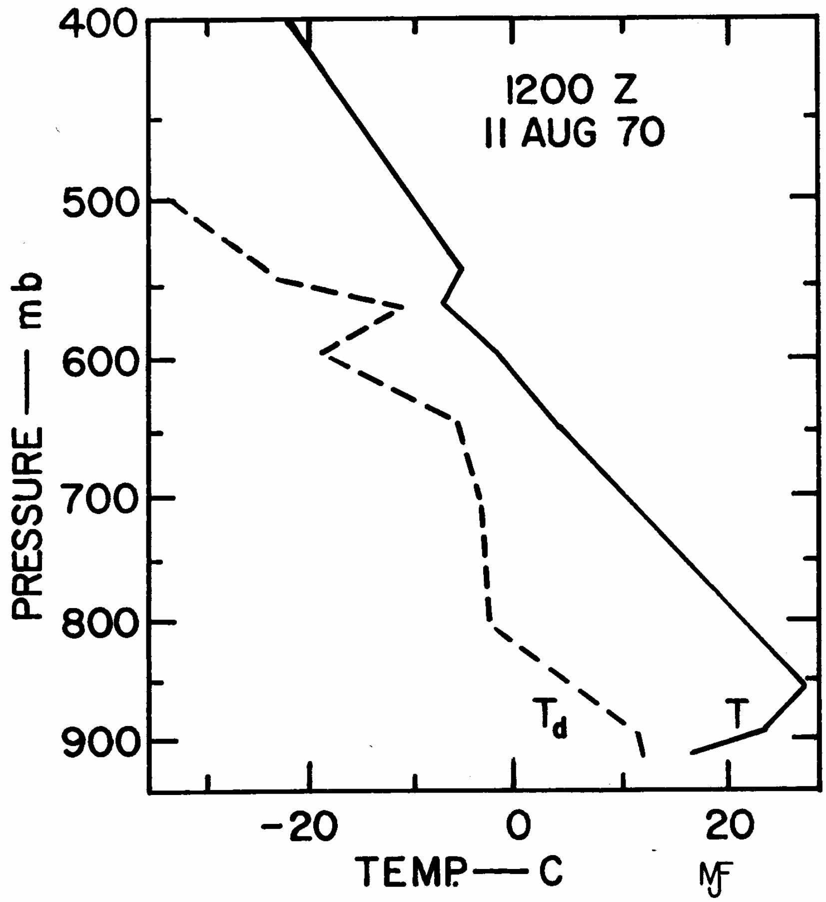

Fig. 9. Rapid City upper air sounding, 1200Z, 11 August 1970.

TABLE 2

Summary of Data from Five T-28 Cloud Penetrations on 11 August 1970

PASS	HAIL	PENETRATION ELAPSED TIME SEC	ALTITUDE SPREAD x 10^3 ft	ALTITUDE MEAN x 10^3 ft MSL	TEMPERATURE MEAN CORRECTED T_c °C	TEMPERATURE MEAN VIRTUAL T_v °C	LIQUID WATER MAX gm m^{-3}	LIQUID WATER MEAN gm m^{-3}	RATE OF CLIMB MAX m sec^{-1}	RATE OF CLIMB MEAN m sec^{-1}	RATE OF CLIMB STD DEV m sec^{-1}	RATE OF CLIMB SPREAD m sec^{-1}	BUOYANCY MAX °C	BUOYANCY MEAN °C
1	No	73	0.6	22.7	-17.9	-17.5	.85	.26	13.7	3.2	3.2	18.8	.08	-.57
2	No	84	0.5	22.1	-16.3	-15.95	1.43	.30	19.8	10.9	3.7	19.5	2.02	.90
3	No	75	0.6	20.2	-13.1	-12.6	.70	.14	9.18	1.84	3.8	14.0	2.18	.82
4	Soft & Slushy	120	3.7	20.3	- 9.3	- 8.59	1.94	1.03	17.6	8.24	4.7	18.5	4.23	2.19
5	Hard	358	5.2	23.1	-17.0	-16.65	0.83	.18	19.3	4.1	4.8	28.1	2.68	1.6

Computer generated displays (Boardman et al., 1970) of the radar data at 1242 and 1253 MDT represent the storm before and after the fourth penetration (1249:00-1251:00 MDT) and are included as Figs. 10 and 11.

The arrow at the left in each figure represents the altitude at which the T-28 penetrated the storm. The vertical section is represented on the horizontal section by the straight line in the lower portion of each figure and corresponds to the penetration path of the T-28.

Between the 1242 and 1253 MDT displays there is a noticeable decrease in the maximum altitude of the strong reflectivity area, which represents an estimated 5 m sec^{-1} descent. During the penetration the average vertical velocity was about 8 m sec^{-1} (Fig. 5). This represents an estimated overall average terminal fall velocity of the high reflectivity zone of about 13 m sec^{-1}. A hailstone 0.65 cm in diameter has a terminal fall velocity of 13 m sec^{-1} at 20,000 ft MSL which correlates well with what was observed during the penetration.

5.4 Discussion of Data

The definitions of variables listed in the various columns of Table 2 are listed in Section 4. The pertinent equations used to obtain these variables are listed in Appendix B.

Four selected variables (altitude, buoyancy, vertical velocity, and liquid water content) were printed on a cathode ray tube for each of the five penetrations and the analog traces were photographed to give a representation of the penetration profiles of these parameters and the capability of the data reduction system (Figs. 2 - 6).

The first three penetrations encountered no hail. Pass four (Fig. 5) encountered soft, slushy hail and pass five (Fig. 6) encountered hard hail.

Figures 2, 3, 4, and 6 indicate a liquid water profile which has a noticeable top-hat character. These moist cores in the cloud do not correlate well with the strong vertical motions encountered during the penetrations. This suggests that the entire updraft area does not consist of liquid water particles of the size measured by the Johnson-Williams liquid water content device. It could either mean that there was less liquid water present or that the liquid water consisted of larger drops, for which the Johnson-Williams device underestimates the liquid water content.

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Please refer to Figs. 10 and 11. The vertical scale on the left hand side of the upper square in both of these figures is marked with tick marks on the left hand side of the square. These tick marks correspond to altitudes ranging from 10,000 ft MSL for the lowest mark to 50,000 ft MSL for the highest mark. The altitude of the aircraft during the times of penetration of the storm was between 18,000 and 27,000 ft MSL.

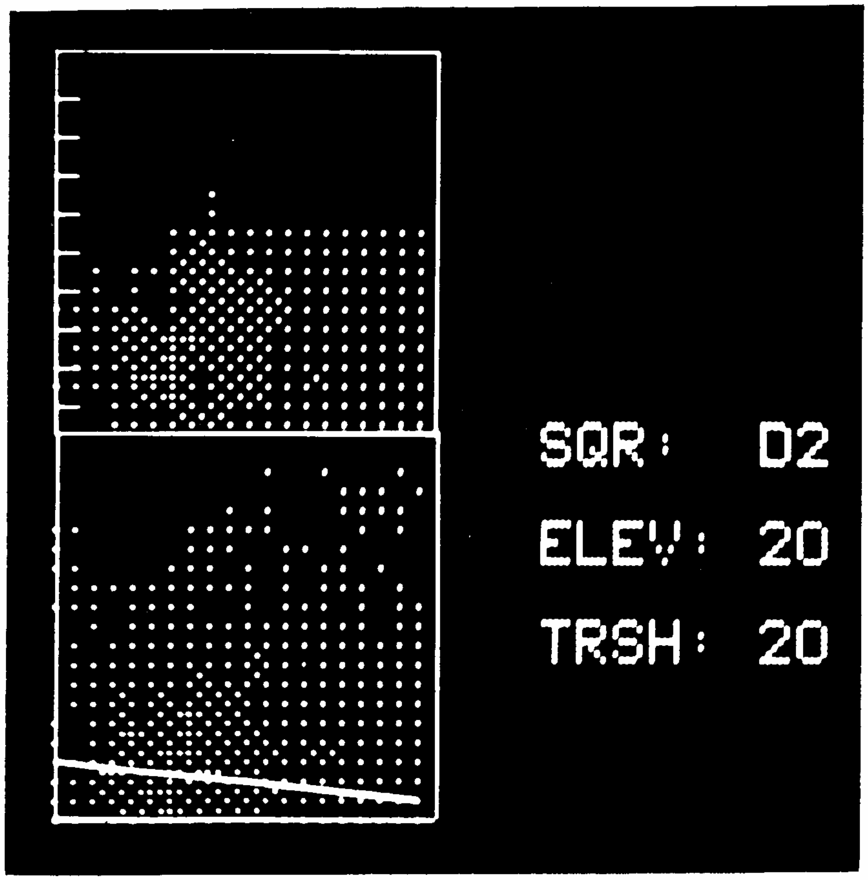

Fig. 10. Computer generated display of radar data for the storm of 11 August 1970 at 1242 MDT. Horizontal section at 20,000 ft MSL with the aircraft path shown in the lower square; vertical section along the aircraft paths in the upper square.

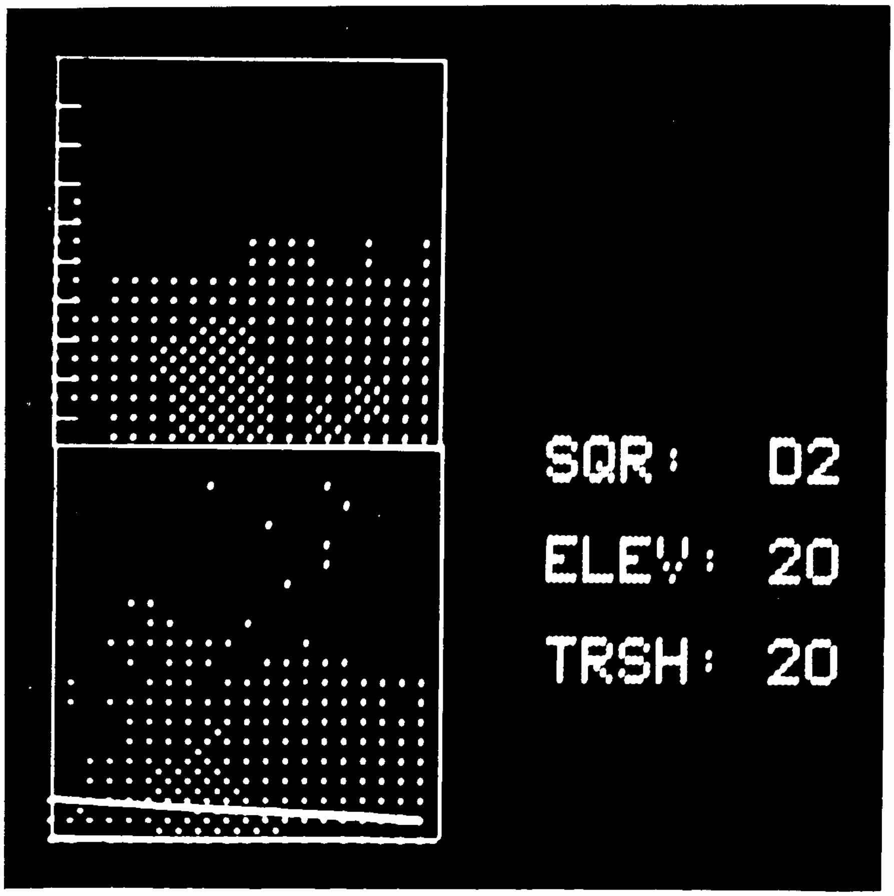

Fig. 11. Computer generated display of radar data of 11 August 1970 at 1253 MDT. Horizontal 20,000 ft MSL with the aircraft path shown lower square; vertical section along the path in the upper square.

Penetration four shows a consistently high liquid water content (mean equal to 1.03 gm m^{-3}). This high liquid water content and the soft, slushy hail encountered correspond well with the radar observations noted in Section 5.3. It is felt that this penetration was made through an area of descending precipitation.

The hard hail encountered during penetration five (Fig. 6) occurred in an area of lower liquid water contents (average, 0.18 gm m^{-3}).

5.5 Aircraft Data Indicative of the Presence of Hail

Referring to Table 2, it is noted that the occurrence of hail seems to be related to:

(1) Penetration elapsed time. The indication is that the longer the penetration time (or the bigger the cloud) the greater the chance of encountering hail.

(2) Altitude spread. The difference between the maximum and minimum altitude is defined as the altitude spread. The large spread on the last two penetrations is positively related to the hail encountered during these two penetrations. This would also imply a sustained strong updraft. This, in fact, is the case as shown in Figs. 5 and 6 on the altitude trace. Figures 2, 3, and 4 do not show this steady overall increase in altitude during the penetration.

(3) Standard deviation of the rate-of-climb. This indicates that storms containing hail have a greater variation in rate-of-climb than those without hail.

(4) Maximum buoyancy. It is reasonable to expect hail producing storms to have greater buoyancy than non-hail producing storms.

(5) Mean buoyancy. It is also reasonable to expect a greater mean buoyancy in hail producing storms.

It is noted that the presence of hail does not appear to be related to:

(1) Maximum liquid water content.

(2) Mean liquid water content. It is noted that the mean liquid water content is roughly related to the mean temperature and mean altitude of the penetration and does not seem to be directly related to the presence of hail. The possible significance of the high mean liquid water content encountered during pass four is discussed in Sections 5.3 and 5.4.

(3) Maximum rate-of-climb.

(4) Mean rate-of-climb. These are indications of the strongest and average updrafts encountered during a penetration. These data are felt to be only a good approximation of the vertical velocity because of the turbulence and constantly changing aircraft attitude. One would expect the presence of hail to be related to the presence of strong updrafts. The limited data reflects no positive relationship of maximum and mean updraft to the presence of hail.

6. SUMMARY AND CONCLUSIONS

A T-28 aircraft was put into operational service and an instrumentation package was developed to gather significant data in hail bearing clouds. Four missions were flown to gather data and the data were reduced to demonstrate the capability of the entire system. The basic analysis scheme has been developed and will be used as the basis for future analysis of T-28 penetration data.

The limited sample of data available provides a basis for a preliminary indication of variables that are related to the occurrence of hail. These are:

(1) Penetration elapsed time.

(2) Altitude spread.

(3) Standard deviation of the rate-of-climb.

(4) Maximum buoyancy.

(5) Mean buoyancy.

The limited data also suggest that certain other variables are not related to the presence of hail during a penetration. These variables are:

(1) Maximum liquid water content.

(2) Mean liquid water content.

(3) Maximum rate-of-climb.

(4) Mean rate-of-climb.

7. FUTURE PLANS

Our experience to date with the T-28 suggests some future requirements and improvements which will make the aircraft a more reliable meteorological platform for the National Hail Research Experiment (NHRE), which is providing support for use of the T-28.

7.1 Airframe

The abusive treatment that the airframe receives during the penetration of thunderstorms requires that it be in the best possible mechanical condition. This will require that the airframe continually be checked for fatigue and damage from turbulence and hail. All possible structural strengthening modifications need to be incorporated into the airframe.

7.2 Engine

It is currently planned to replace the engine with an R-1820-86A engine. This engine is identical to the ones used on military versions of the T-28 and functions with minimal difficulty on military trainer aircraft.

7.3 Hail Sensors

It is essential that hail be measured in both size and quantity with as much resolution as possible. This problem is now being investigated, hence, no conclusions have yet been drawn as to the best approach. The 1972 operational season should see a minimum of two prototype devices for measuring hail from the T-28. The concepts under consideration include:

(1) Momentum sensors.

(2) Light interruption.

(3) Camera.

(4) Audio recorder.

7.4 Ice-water Budget

The ice-water budget of hailstorms is an area which we hope to investigate in the future. In addition to the standard Johnson-Williams liquid water meter, plans are to include a liquid water measuring device currently being developed by Dr. Tom Kyle of NCAR as part of the T-28 instrument package.

Devices such as the foil impactor and the formvar replicator would be desirable additions to aid in the study of the ice-water budget.

7.5 Updraft Structure

A refinement to the vertical velocity measurement scheme is planned. It is planned to record the manifold pressure in addition to altitude, airspeed, and vertical velocity. The addition of manifold pressure can be used to give a better estimate of the actual vertical velocities encountered.

7.6 Supporting Observations

High resolution meteorological radar data are essential for interpreting the data obtained with the T-28 during thunderstorm penetrations. A radar tracking system capable of tracing the T-28's track is also required to relate the radar data to the aircraft data for analysis. The above items also should be available on a real-time basis so that aircraft vectoring can be provided.

Concurrent observations from the ground (including rainfall and hailfall), and data from other aircraft will be helpful in relating these observations to what actually exists in the cloud as measured by the T-28. The observational network planned by the NHRE should provide excellent supporting data to interpret the information obtained by the T-28.

7.7 Data Analysis

The same general scheme (partially developed under this grant) used in reducing data for this report is planned for future years. The system of using PDP-8 computer programs to put the data into engineering units seems to be a satisfactory and economical approach.

A capability is being developed for writing the data on industry compatible magnetic tape. The CDC 3400 computer, currently on the campus of the South Dakota School of Mines and Technology, can then be used for some of the data analysis. This will also make it feasible for other NHRE participants to use the T-28 data.

Plans are to use the T-28 as part of the NHRE. Aircraft penetrations are to be used as part of the overall experiment and the data correlated with other NHRE data. The long-term objectives are to determine:

(1) The updraft structure in regions of hail formation.

(2) The composition of high radar reflectivity zones.

(3) The ice-water budgets of hail-producing regions.

8. REFERENCES

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APPENDIX A

Man Months Expended on T-28 Project
NSF Grant GA-24651
1 May 1970 - 1 May 1971

Name	Title	Months Worked Under Referenced Contract
Professional		
Richard A. Schleusener	Director	1.70
John H. Hirsch	Research Meteorologist	2.95
William G. Myers	Research Engineer	6.47
Lawrence B. Youngren	Pilot Climatologist	9.31
James H. Boardman	Junior Research Engineer	.82
Paul L. Smith	Head, Engineering Group	.38
Wayne R. Sand	Pilot	.86
		22.49
Other		
Joie Robinson	Secretary	.38
Edward R. Galles	Electronics Technician, Chief	.02
Kenneth Jasper	Electronics Technician	6.93
Gary A. Weishaar	Student	.07
Roman L. Zylla	Student	1.62
		9.02
Total Man-months		31.51

APPENDIX B

Equations used in the deviation of variables considered in the analysis.

1. Altitude

$$Z = \frac{T_o}{\gamma} \left[1 + \left(\frac{P}{P_o}\right)^{\gamma R} \right]$$

Z = Altitude of the aircraft in feet.

T_o = Standard sea level temperature, 288C.

γ = Standard temperature lapse rate, $0.0065 Cm^{-1}$.

P = Pressure at altitude Z in inches Hg.

P_o = Standard sea level pressure, 29.921 inches Hg.

R = Gas constant for dry air.

2. Corrected Temperature

Cloud temperature is derived from the measured temperature after the compressional heating correction has been applied and a moist adiabatic ascent or descent to the mean altitude of the penetration. The equation for this calculation is:

$$dT = - \frac{\frac{g\Delta Z}{C_p} \left(1 + \frac{q_s L}{RT} \right)}{1 + \frac{\varepsilon L^2 q_s}{C_p R T^2}}$$

Where:

g = Acceleration due to gravity.

ε = Molecular weight ratio.

ΔZ = Height change to get to mean altitude.

L = Latent heat of condensation.

C_p = Specific heat of dry air.

q_s = Saturation mixing ratio.

R = Gas constant for dry air.

T = Measured temperature corrected for compressional heating.

APPENDIX B (Continued)

3. Virtual Temperature

Cloud virtual temperature is derived from the cloud temperature by:

$$T_v = T_c \left(\frac{1 + q_s}{\varepsilon(1 + q_s)} \right)$$

Where:

T_c = Corrected cloud temperature.

q_s = Saturation mixing ratio.

ε = Molecular weight ratio.