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SUMMARY OF T-28 FIELD OPERATIONS - 1976

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1. INTRODUCTION

The Institute of Atmospheric Sciences (IAS) of the South Dakota School of Mines and Technology provided an armored T-28 aircraft for participation in the 1976 National Hail Research Experiment (NHRE) under a continuation of Subcontract No. NCAR 182-71. The T-28 participated mainly in the mature storm studies of the NHRE field program as outlined in the National Hail Research Experiment Operations Plan 1976.

The objectives of the T-28 research are consistent with NHRE objectives to locate and characterize the hailstone growth region in various types of storms. The specific IAS objectives are:

1) Determination of particle size distributions in various stages of thunderstorm/hailstorm development;

2) Using the particle size measurements as input for further numerical model developments;

3) Determination of ice/water budgets in hailstorms; and

4) Identification of the relative importance of the collision/coalescence and Bergeron processes in the formation of hail embryos.

2. FLIGHT OPERATIONS SUMMARY

The T-28 and associated personnel moved to Laramie on 3 May in order to complete preparation for the beginning of the 1976 field season. Prior to this time, eight aircraft familiarization flights and three instrumentation test flights were made in the Rapid City area. Ten test flights were made in the Laramie area during May and research flights began on 4 June. A total of 18 research flights were made in June and July with 60 cloud penetrations. One research flight was missed on 2 June due to an inoperative fuel boost pump. A summary of the 1976 flight operations is included as Table 1.

Basing the T-28 from the University of Wyoming's hangar at Laramie proved to be an excellent arrangement in several respects. The hangar with associated shop and office facilities is significantly better than could be located anywhere else in the area. Consolidation of two bases of operation into one simplifies numerous logistic and operational problems. There is a beneficial transfer of information between personnel of the University of Wyoming and South Dakota School of Mins and Technology associated with NHRE. Finally, taking off from Laramie allowed a straight climb to penetration altitude with little or no loss of time on station. The assistance of the University of Wyoming in making their facilities available to us is greatly appreciated.

The installation of the base radio facility for the last two weeks of the season proved very helpful for relaying status reports both to and from Grover.

The radar control and tracking system worked well during most of the season, but some penetrations were lost due to outages of the M-33 track radar. The FAA controller at the Grover site proved its worth several times, but especially when communications were lost with the ARTCC. For future use it may be of some value to have direct two-way communications with the FAA controller located at Grover, rather than going through a third party.

TABLE 1

Summary of Flight Operations - April through August 1976

Flt. No.	Date	Time (hrs)	Approx. Research Time Block	Penet.	Cannon Camera or Hail Sensor	PI Tape	Pertec Tape	Voice Tape	Remarks
149	4-23	1.0			Cannon Camera				Cannon Camera test
150	4-23	0.7			Cannon Camera				Cannon Camera test
151	4-28	1.1				Yes		Yes	Instrument test
152	5-3	1.9							Ferry A/c to Laramie
153	5-11	1.8			Cannon Camera	Yes	Yes	Yes	Instrument & Cannon camera test
154	5-12	0.8			Cannon Camera	Yes	Yes	Yes	Alcohol/foil impactor clear air test
155	5-14	1.2			Cannon Camera	Yes	Yes	Yes	Alcohol shedding test
156	5-18	1.1			Cannon Camera	Yes	Yes	Yes	Alcohol/ice shedding test
157	5-18	0.6							Check transponder altitude reporting
158	5-19	1.0							Transponder repair at Cheyenne
159	5-19	0.9			Cannon Camera	Yes	Yes	Yes	Alcohol/ice shedding test
160	5-26	0.9				Yes	Yes	Yes	Instrument and encoding altimeter test
161	5-26	2.1				Yes	Yes	Yes	Track radar/comm. test. area familiarization
162	6-4	2.3				Yes	Yes	Yes	Tower fly-by
163	6-4	1.7	1739-1830	5	Cannon Camera	Yes	No	Yes	Research
164	6-8	2.6	1430-1545	8	Cannon Camera	Bad	Yes	Yes	Research - First echo study
165	6-8	1.0				Yes	Yes	Yes	Research - No penetrations - storm dissipated
166	6-21	2.0	1815-1850	5	Cannon Camera	Yes	Yes	Yes	Research
167	6-22	2.2	1600-1700	3	Hail Sensor	Yes	Yes	Yes	Research
168	6-30	1.5	1830-1850	4	Hail Sensor	Yes	No	Yes	Research
169	7-1	0.8				Yes	Yes	Yes	Research - No penetrations - no oxygen
170	7-1	0.7				Yes	No	Yes	Research - No penetrations - Pertec recorder quit
171	7-2	0.4				Yes	Yes	Yes	Instrument test
172	7-2	1.3	1650-1700	1	Cannon Camera	Yes	Yes	Yes	Research - No M-33 track
173	7-6	1.7				Yes	Yes	Yes	Research - No penetrations - no M-33 track
174	7-7	1.7	1715-1740	2	Cannon Camera	Yes	Yes	Yes	Research - No M-33 track
175	7-13	1.0							Maintenance test
176	7-14	2.2	1500-1540	5	Cannon Camera	Yes	Yes	Yes	Research
177	7-16	1.1							VOR/DME repair Cheyenne
178	7-17	0.8				Yes	Yes	Yes	Research/heading calibration - No penetrations - storm dissipated
179	7-18	1.9	1710-1745	3	Hail Sensor	Yes	Yes	Yes	Research
180	7-20	2.4				Yes	Yes	Yes	Tower fly-by
181	7-20	1.6	1710-1800	5	Cannon Camera	Yes	Yes	Yes	Research
182	7-21	1.9	1650-1730	6	Cannon Camera	Yes	Yes	Yes	Research
183	7-22	2.2	1630-1725	6	Hail Sensor	Yes	Yes	Yes	Research
184	7-25	2.1	1750-1835	3	Hail Sensor	Yes	Yes	Yes	Research
185	7-30	2.0	1740-1835	4	Cannon Camera	Yes	Yes	Yes	Research
186	7-31	1.7							Jeffco - Static display
187	7-31	1.3							Ferry Rapid City

Totals:

Total Number of Flights	39
Total Aircraft Hours	57.2
Total Number of Cloud Penetrations	60

3. INSTRUMENTATION PERFORMANCE

In general, the T-28 instrumentation package performed its data gathering function well throughout the 1976 season. On numerous occasions, component failures or human errors contributed to less than 100% performance; but due to the redundancy built into the system, there was only one day during which all data were lost due to hardware failure.

A summary of the performance of each system component follows. Comments regarding the quality of data gathered are subject to change after more thorough analysis.

3.1 Data Recording System

Both the Monitor Labs 9100 and Particle Measurement Systems (PMS) digital recorders experienced some hardware failures during the project but, fortunately, we were able to fix these problems in fairly short order. Recorder failures caused loss of some data on 4 of the 18 research flights. The most serious and frustrating problems which occurred with the 9100 involved power line transients. It was discovered that the power-up sequence of various inverters aboard the T-28 can cause logic circuits in the 9100 to "hang up" which results in virtually complete loss of data from an entire flight. This happened on one occasion, and the fix involved changing our power-up sequence prior to flight. A similar "hang up" that occurred on two other occasions was found to be due to poor electrical contacts on one printed circuit assembly.

The PMS recorder, which records all digital and some analog data from instruments on the T-28, was down on two occasions. The 70-amp inverter which provides power to the PMS system failed early in June and had to be returned to the factory for repair. We were able to locate a "loaner" inverter as a temporary replacement for the original, and the system was down for only two days. The second failure involved the end-of-tape sensor. This problem caused the PMS system to shut itself down prematurely. After the cause was discovered, a simple bypass of the end-of-tape sensor brought the system back up.

The voice/hail mike recorder operated well during the season. In the past, the main problem has been keeping a small voice recorder operating in this type of environment, but the Sony stereo recorder used in 1976 seems to be rugged enough. So far we have not experienced any mechanical failures; however, it was necessary to redo the hail mike cable and install a new ground strap on the recorder so that both the voice and hail channels would be recorded clearly. A modification (Hi-Pass filter) was also added to the hail channel to increase the hail signal-to-engine noise ratio. The quality of audio now recorded, both hail and voice, is the best it has ever been.

3.2 Particle Measurements

The system carried on the T-28 for measuring sizes, numbers, and composition of airborne particles consists of the PMS forward-scattering (FSSP) and 2D probes, the IAS hail sensor, the Cannon camera, and the foil impactor.

The PMS probes were plagued with numerous problems during the whole month of June due to failures in the recording system and in the probes themselves. A great deal of work was done to improve the probe performance, and during the second half of the season (nine research flights) the units worked very well. One problem which occurred in the PMS system involved the optical arrangement of the 2D probe. After viewing data from this probe, it was first thought there was an error in airspeed compensation causing the particles to appear flattened. However, the problem was found to be in the optics and the probe had to be returned to the factory for rework. During Flight 164 on 8 June, the FSSP optics were knocked out of alignment, presumably by a hailstone impact. This was not immediately discovered, but the problem was corrected prior to the next research day (21 June).

During the first two flights on which the IAS laser hail sensor was flown, it categorized particles too large. The data looked as though a great deal of large hail had been encountered, but this could not be substantiated by any of the other data, including pilot comments. The problem was the result of low output from the laser light source and was corrected by replacing the original 2-milliwatt laser tube with a 5-milliwatt unit. Since the laser hail sensor and the Cannon camera cannot be flown at the same time on the T-28, it was some time later in the season before the sensor was flown again. After the replacement of the laser and subsequent realignment of the optics, the sensor appeared to function properly. Subsequently, the hail sensor was carried on three research flights for a total of 12 penetrations, several of which were into regions of significant hail concentrations.

It appears that some data contamination may now exist due to shedding of ice and rain from the nose of the hail sensor pods. We are investigating the possibility of modifying the sensor into a two-dimensional device similar to the PMS 2D probe, which would eliminate the uncertainty now existent in some of the data. For the present, the uncertainty can be reduced by comparing hail sensor data with foil data, PMS data, and radar data, but the only sure fix is to convert the sensor to a 2D imaging probe.

The Cannon camera (Fig. 1) came through its first operational season in great shape and it appears to have provided much good data.

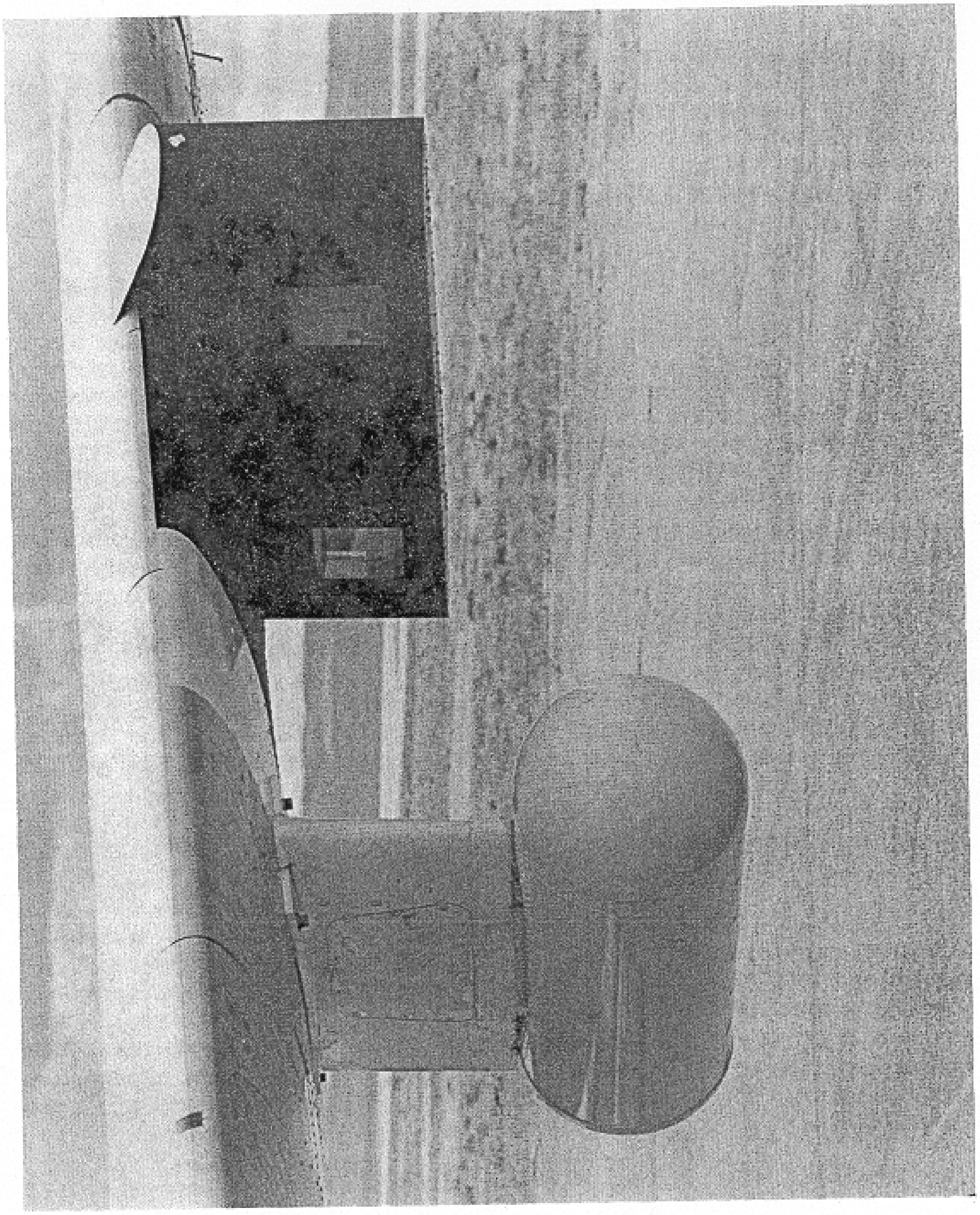

Fig. 1. View of Cannon camera mounted on T-28.

Some data were lost due to incorrect airspeed compensation and optical alignment problems but, in general, the camera performed well. A sample of the output from the Cannon camera system is shown in Fig. 2.

The foil impactor has had problems with streaking of the foil ever since it was put on the T-28. The problem was found to result from liquid water freezing on the first foil guide idler roller on the take-up side of the machine. When the idler was removed, the streaking problem diminished. However, this roller also acted as a "squeegee" to remove excess liquid water from the exposed foil. Removal of the idler allowed the excess water to freeze onto the foil and accumulate on the take-up spool, causing some foil contamination. It was also found that this idler is necessary whenever the take-up reel gets full to prevent jamming the mechanism and burning out the drum motor. The motor finally did burn out during Flight 183; it was replaced on 24 July. For future research seasons with the foil impactor, we will have to develop new procedures to clean excess water off the foil, as well as to minimize the probability of motor failure.

3.3 Pressure Instruments

The T-28 pressure measuring devices include the Rosemount absolute and differential pressure transducers, Ball altimeter, Giannini manifold pressure transducer, and a times five (X5) amplifier for the Rosemount absolute pressure. No serious problems were encountered with the pressure devices. The Ball altimeter showed discontinuities in its output voltage throughout the season. This transducer is considered to be a secondary measurement device, so no effort was made to fix it during the season. The X5 amplifier failed as a result of a cold solder joint connection, which was fixed as soon as the failure became apparent.

3.4 Temperature Instruments

The NCAR reverse flow and Rosemount temperature probes worked well throughout the season and no problems were encountered. This was the first year in which the Rosemount sensor performed well and this was due to the replacement of the bridge amplifier. (The original amplifier used with this probe was not designed for aircraft use.) The deicing power was shifted from the Rosemount probe to the angle-of-attack probe, so that erroneous temperature readings occur under icing conditions, but otherwise the agreement between the two temperature sensors was very good.

3.5 Liquid Water Concentration and Icing Rate

The Johnson-Williams (JW) liquid water concentration indicator and the Rosemount ice detector were both damaged, possibly by

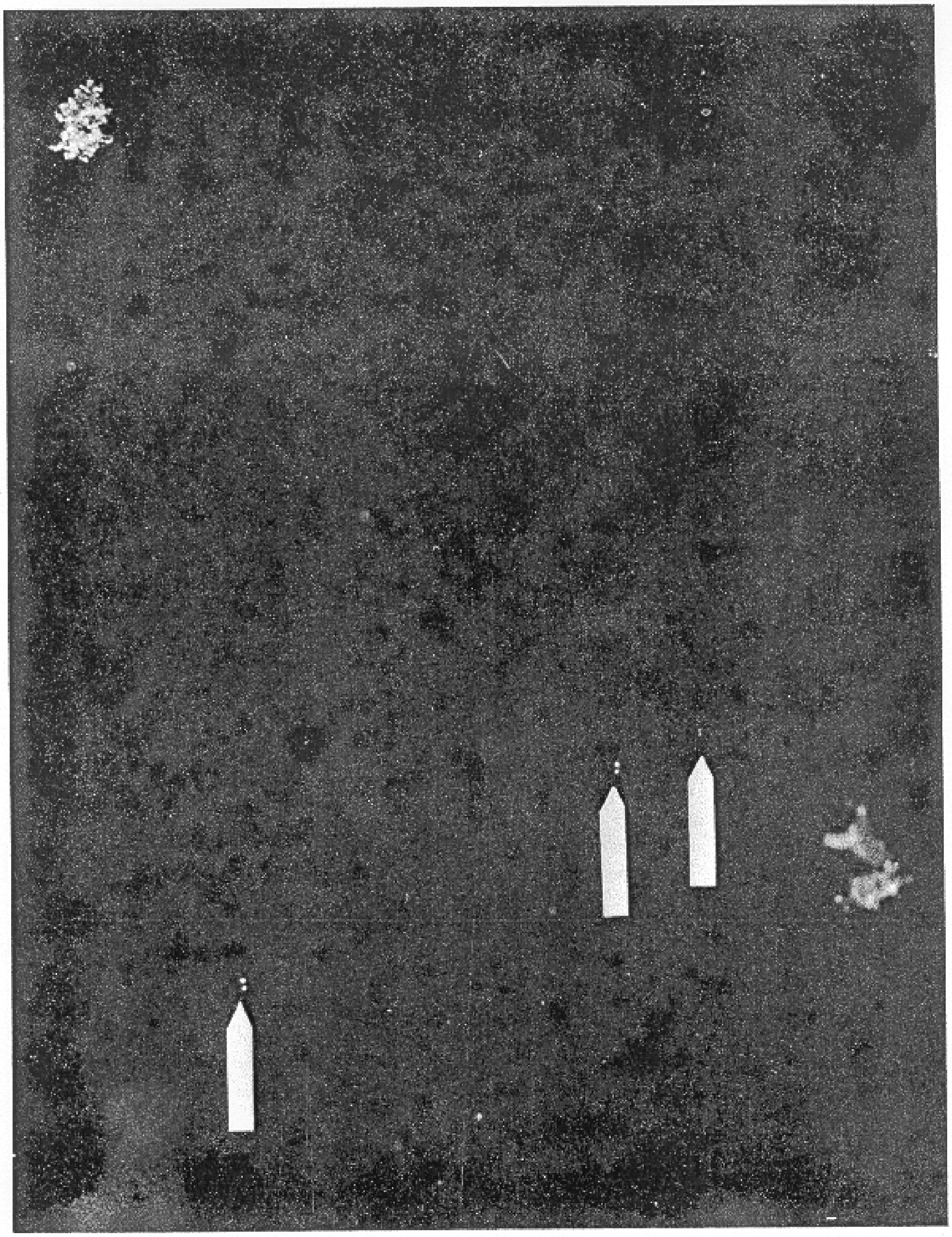

Fig. 2. Example of output from Cannon camera.

hailstone impacts or ice shedding during the season. The JW was quickly repaired by replacing the sensing element, but the ice detector could not be repaired. We were able to obtain a "loaner" from Rosemount late in the season and the new probe worked very well. We will need to purchase a new ice rate detector if this type of measurement is to continue. The new probe made by Rosemount is field repairable, so we will not have to run the risk of having this type of failure occur again.

3.6 Rate of Climb

The Ball variometer used to measure rates of climb worked normally throughout the season, but it was discovered that the output voltage linearity is poor at rates of climb or descent greater than ±3000 ft min^{-1} (about ±15 m sec^{-1}). This presents some problems to the analysis of data for large updrafts. We have returned the variometer to Ball Engineering for a calibration check, and from this calibration a new equation for converting raw data to engineering units will be generated. If the linearity of this device cannot be improved, we may have to replace it with a newer and more accurate unit.

3.7 Heading Indicator

The heading indicator was flown successfully for the first time during the 1976 season. The calibration curve of this unit was also found to be nonlinear, but a table look-up routine was generated which gives heading data to an accuracy of better than ±2°. We cannot adjust the device to improve its linearity, so this routine will have to be refined if more accuracy is to be obtained.

3.8 Angle of Attack

The 1976 field season was also the first during which angle of attack (Fig. 3) was measured aboard the T-28. The vane is a military device originally intended for use on jet aircraft. Output from this vane is linear with angle and has a resolution of about 0.025° over the range of ±15°. No problems were encountered with the instrument.

3.9 Acceleration

The Humphrey vertically stabilized accelerometer was modified from the previous season so that its output during straight and level flight would be zero volts. This modification changed the range of acceleration measurement from ±2 g's to -1 to +3 g's, which is more in line with the range expected to be encountered. The accelerometer worked well throughout the season, although it became apparent by late July that the gyro bearings were getting worn. The unit is to be returned to the manufacturer for inspection and repair, if necessary, before the next research season.

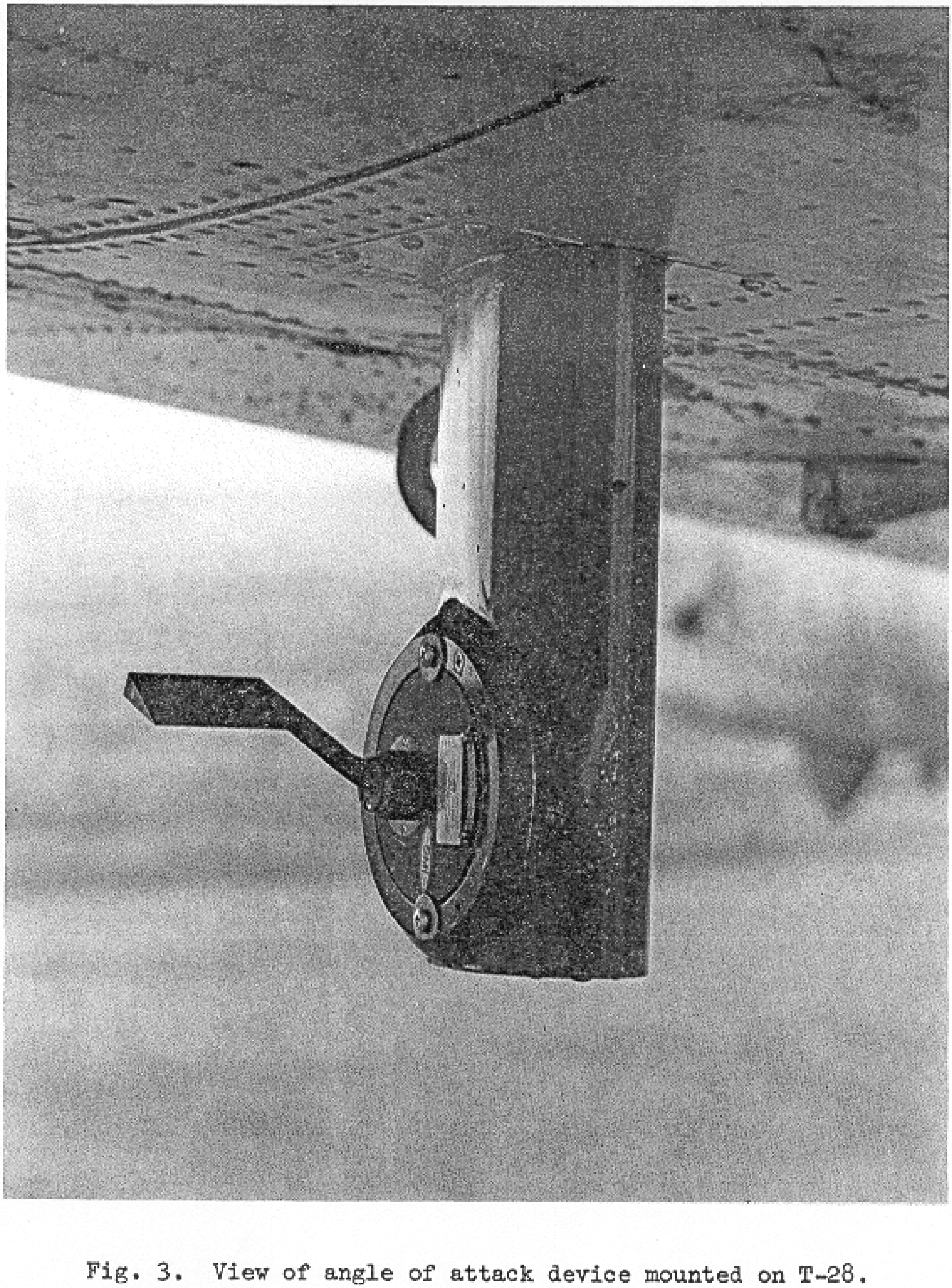

Fig. 3. View of angle of attack device mounted on T-28.

3.10 True Airspeed

The NCAR True Airspeed (TAS) computer performed within specifications all season, as long as the T-28 telemetry transmitter was not operated. The RFI susceptibility of this computer is very high and several attempts at reducing it were unsuccessful. It appears that the sensitivity is a result of the changes put into the circuitry during the past winter. We recommend that this device be modified once again so that the telemetry system can be operated.

3.11 Precipitation Sampler

The mouse trap precipitation sampler was again tested on the T-28 and once again the collection bags failed. This device in its present configuration apparently cannot withstand the environment through which the T-28 flies. A redesign of the instrument is indicated.

3.12 Radio Navigation

The VOR and two DME's which the T-28 carries have worked reasonably well in the past, but the reliability and calibration stability are now becoming quite poor. DME 2 was plagued with persistent sensitivity problems. As a secondary position indicator, this system works well, but if we are to depend on the data in the future, we should replace at least one of the DME units.

3.13 Side-looking and Windscreen Cameras

The side-looking cloud camera worked very well as in previous seasons and turned out to be very valuable in explaining the icing characteristics of the NCAR "ice free" temperature probe. This temperature probe was flown three times during the season and iced up significantly each time.

The windscreen camera, a new addition to the T-28 camera system, turned out to be a total failure. It had been hoped that the splashes of rain and hail on the windscreen would be clear enough to see on film to get some idea of particle sizes, but mechanical vibration caused by the engine prevented that initially. After the vibration problem was solved, we found that the only time splashes of any type could be seen on the film was when the background light level was quite high. This rarely occurs during cloud penetrations, so it appears that the concept will not work unless a different lighting arrangement is used.

3.14 Telemetry System

The T-28 telemetry system was expanded during the season to provide more operational utility and back-up recording capability. We added subcarrier oscillators to the system so that the project meteorologist at Grover could get real-time data from the rate of climb and altitude transducers, in addition to hearing the pilot's voice comments. The channel capacity of the analog-to-digital converter was also expanded so that all of the analog data could be recorded at Grover.

The system could not be used during the season because it interfered with the operation of the TAS computer. Telemetering of data to Grover for real-time use and back-up recording is an important function. We hope that it can be attempted once again as the TAS computer is modified.

3.15 Rapid Recall

The tape recorded data from the T-28 were shipped by bus to Rapid City (9100 tapes) and by courier to NCAR (PMS tapes) for the generation of rapid recall plots on a 24-hour turnaround basis. Samples of the 9100 output are shown in Figs. 4 and 5, and a copy of microfilm output from the 2D PMS tapes is shown in Fig. 6. The recall system worked well, although we were not always able to get the desired 24-hour turnaround. Data from the NCAR computer reduction of the PMS tapes were hand carried back to Laramie, whereas the reduced 9100 data were transmitted back to Laramie and Grover via Xerox telecopier. Although this technique works, we are limited to next day turnaround at best, and this is sometimes too late if equipment problems occur. We believe that a minicomputer should become a part of the ground equipment for the T-28 so that immediate data reduction can be accomplished.

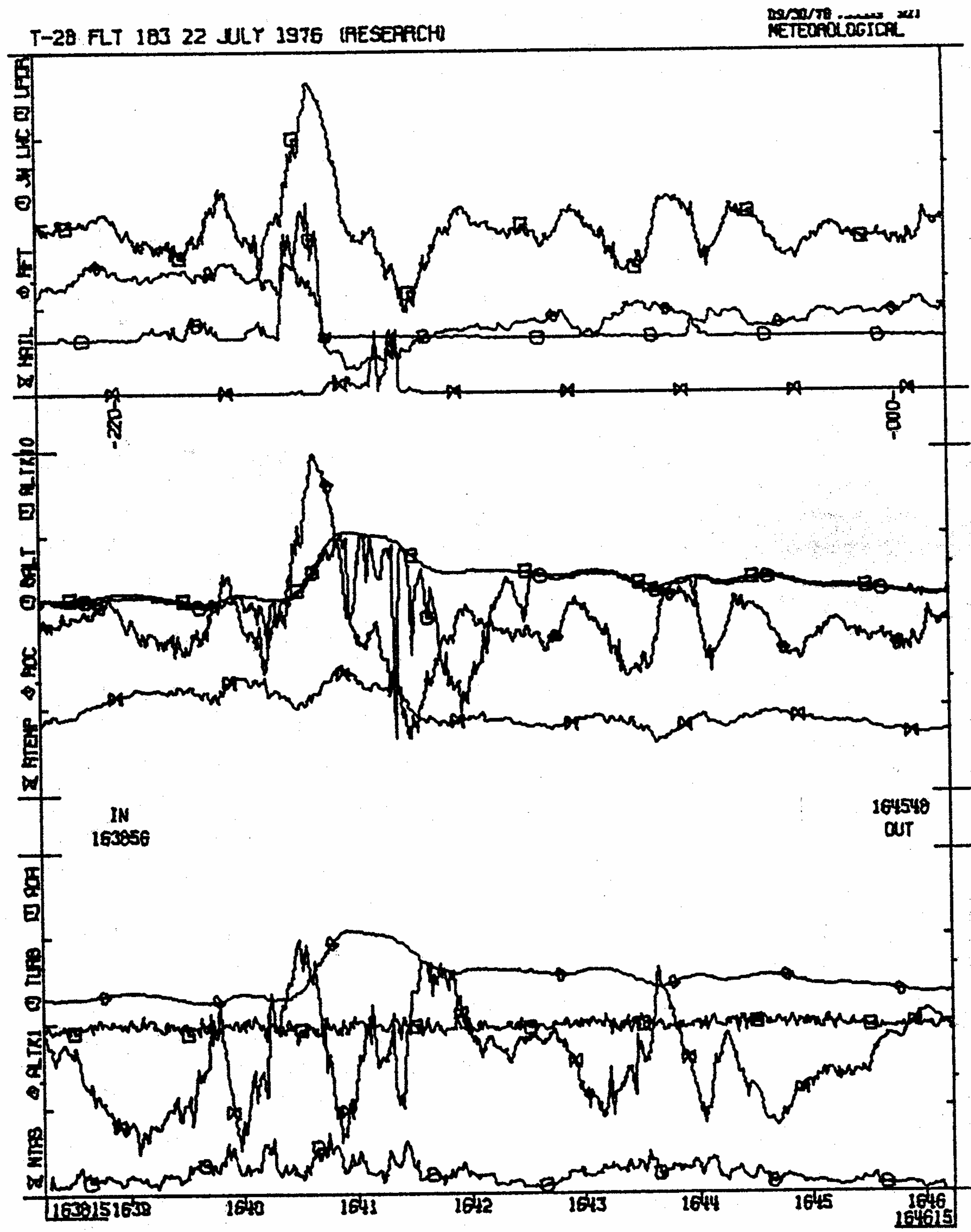

Fig. 4. Example of reduced meteorological data from Rapid Recall output of Flight 183.

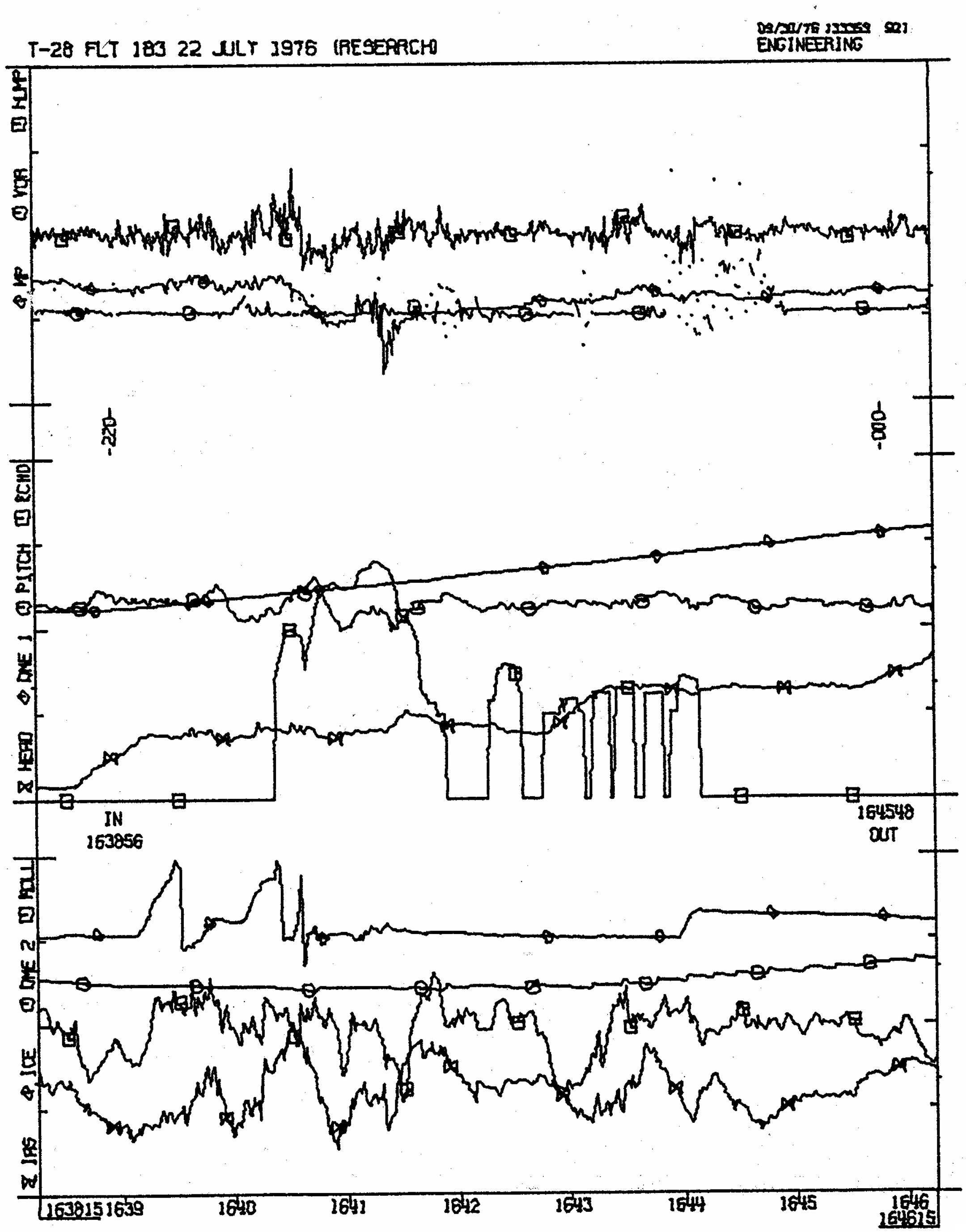

Fig. 5. Example of reduced engineering data from Rapid Recall output of Flight 183.

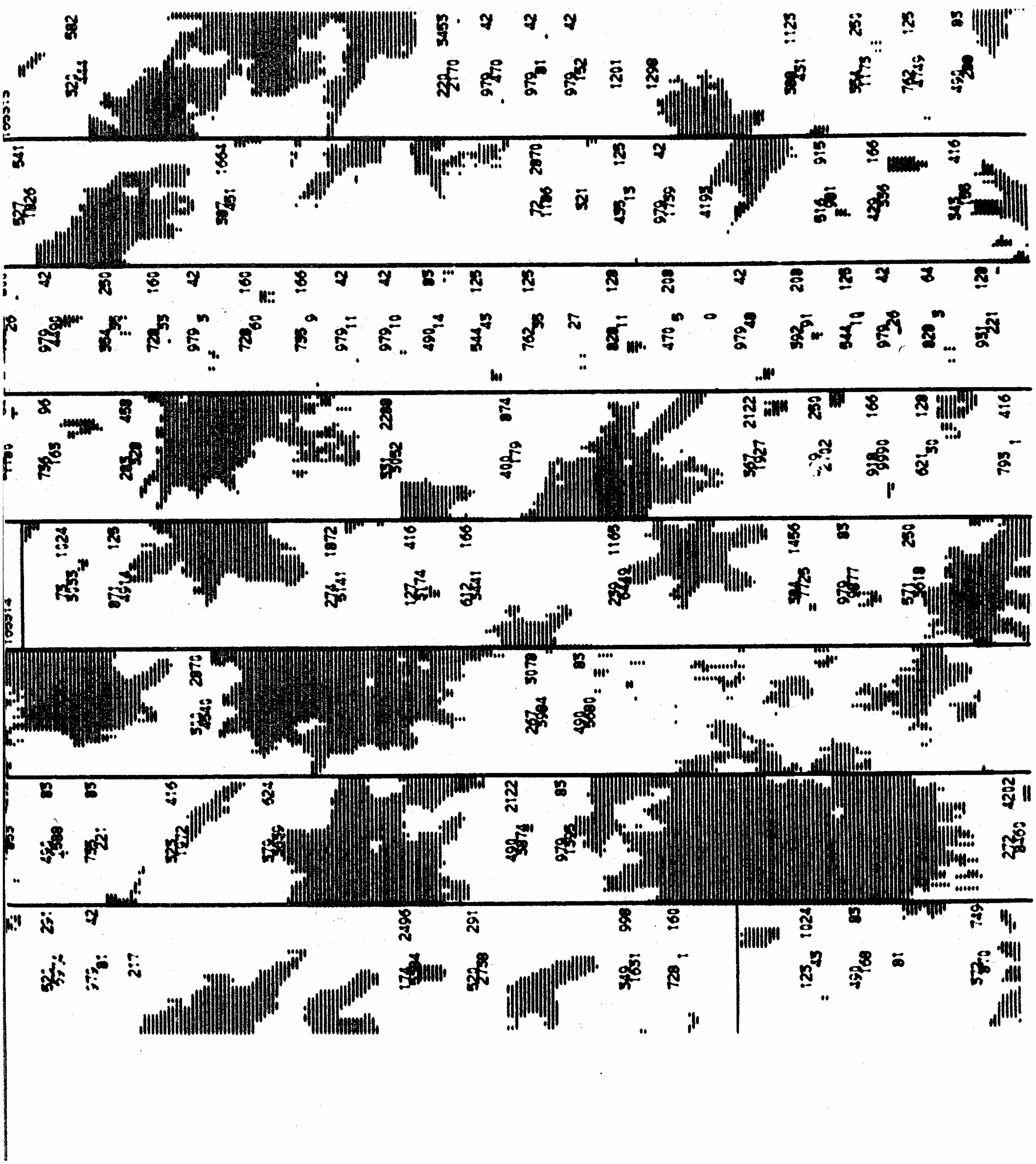

Fig. 6. Typical example of output from PMS two-dimensional device.

4. SUMMARY OF OPERATIONAL DAYS

A total of 60 penetrations were made on 18 research flights during the 1976 field season. The general classifications of the storms penetrated were multicellular, even though several had well developed vaults for certain periods of their existence. The general impression of the storms as viewed from Grover by the project meteorologist was that they tended to be more short-lived and less numerous than in past seasons, in spite of the fact that the operating area was much larger than in the past.

The operational days have been ranked from the viewpoint of the T-28's contribution to the NHRE project, to help assess which days might become the most likely candidates for case studies. The ranking included such things as the pilot's evaluation of the storm, the status of the data gathered, and a storm evaluation by the meteorologist located at Grover.

The following is a ranking of the operational days arranged in descending order of importance:

1. 22 July
2. 25 July
3. 14 July
4. 22 June
5. 21 June
6. 8 June
7. 4 June
8. 21 July
9. 20 July
10. 18 July
11. 30 July
12. 30 June

Active hail days occurred on 8, 21, and 22 June and 2, 14, 22, and 25 July. Of these days, 2 July was not considered in the ranking because numerous tracking problems and power failures at Grover prevented making penetrations on that day. As a result, an excellent storm was missed. June 8 was included in the ranking even though the most active hailstorm was not penetrated. The T-28 had been committed to an early afternoon operation for first echo studies and was in turnaround mode when the active hailstorm developed. Then the storm dissipated before the T-28 could reach it after refueling. In spite of this, 8 June is one of the better days according to our ranking system, because of penetrations prior to first echoes in cloud that ultimately became part of the hail case.

Equipment problems prevented making penetrations on 1 July, while the storm dissipated prior to making any penetrations on 17 July. July 1, 6, and 7 were characterized by weak and disorganized storms and were plagued by M-33 tracking problems at Grover, so that no penetrations were made on these days. Hence, none of the above days were included in the ranking.

The following are brief descriptions of the best six days ranked. Storms below rank 6 tended to be weak and disorganized with short lifetimes and generally quite low reflectivity factors, and as such will not likely become major case studies.

22 July - An excellent storm with all data systems up. Hail reported on the ground and in the air. Vaulted storm with strong updrafts. Some penetrations were in the weak echo region and some in the maximum reflectivity areas.

25 July - A very good storm located just outside the operating area to the south. Hail was reported at the ground and in the air. Good updrafts with characteristics similar to those on 14 July.

14 July - Very good day. Development occurred along a dry line in the Portable Automated Mesonetwork. Hail reported even though the storm did not appear to be particularly strong visually. Excellent Cannon camera images.

22 June - Good storm, hail encountered. Storm was vaulted. No foil impactor data for this day and PMS probes had some problems.

21 June - A fairly good day even though no hail was reported. Updrafts seemed unusually strong.

8 June - T-28 mission supported a first echo flight. Operator error with the 9100 recorder caused all analog data to be missed, but PMS recording was good. Large amounts of hail fell later in the afternoon but did not last long enough for penetrations to be made in the storm. This day indicated strong increases in the upper level winds and the storm later in the afternoon may have shown some super-cell characteristics in spite of its short lifetime.

ACKNOWLEDGMENTS

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