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SUMMARY OF T-28 FIELD OPERATIONS - 1975

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1. BACKGROUND AND OBJECTIVES

The Institute of Atmospheric Sciences of the South Dakota School of Mines and Technology contracted with the National Hail Research Experiment to provide an armored T-28 aircraft to obtain data within hailstorms during the 1975 limited field season.

The T-28 has been developed over the last several years to gather data from the interior of hail bearing thunderstorms. The 1975 season was intended to test some new developments in the T-28 data system in preparation for full research seasons in future years.

The specific objectives for the 1975 summer field season were:

1) To test the T-28 system in preparation for the planned full research year of 1976.

2) Measurement and analysis of the total water content of hailstorms in terms of distribution with size and phase.

3) Preliminary investigation of T-28 data for detection of seeding effects.

2. FLIGHT OPERATIONS SUMMARY

The actual operations of the T-28 were programmed to include about twenty hours of flight time prior to the season in testing and calibrating instruments and about thirty hours of flight time during the month of July in actual data acquisition and further equipment testing. These goals were achieved. A summary of flight operations during this contract period is included as Table 1. The PI and TM at the heads of columns in Table 1 stand for the Precision Instruments on board recording system and the telemetry system, respectively.

TABLE 1

Summary of Flight Operations

Flt. No.	Date	Time (hr)	Penet.	Approx. Research Data Time	PI Tape	Pertec Tape	Voice Tape	TM Tape	Remarks
101	4-18	1.0							Maintenance test
102	4-21	1.5							Maintenance test
103	4-22	0.9							Maintenance test
104	4-23	1.8							Vibration analysis and
105	4-24	1.3							gear retraction tests at Jefco
106	4-24	1.2							
107	5-13	1.3							Install encoding altimeter and
108	5-14	1.4			Yes				calibrate VOR/DME system at Cheyenne
109	6-3	0.8			Yes				Instrument test
110	6-4	1.5							Flight check Knollenberg gear and
111	6-7	0.8							Cannon camera at Jefco
112	6-7	1.5							
113	6-13	1.2			Yes		Yes		Instrument test
114	6-24	1.2			Yes	Yes	Yes		Instrument test
115	6-26	1.7			Yes	Yes	Yes		Instrument test and radar track
116	6-26	1.2							test with Grover radar
117	7-6	2.0		1600	Yes		Yes		Ferry A/C to Cheyenne
118	7-7	1.8	7	1700	Yes	Yes	Yes	Yes	Research
119	7-11	1.0	1	1900-2000	Yes	Yes	Yes	Yes	Instrument test/research
120	7-13	1.9			Yes	Yes	Yes	Yes	Instrument test
121	7-14	1.9	6	1425-1620	Yes	Yes	Yes	Yes	Research
122	7-15	1.8	5	1500-1645	Yes	Yes	Yes	Yes	Research
123	7-16	1.9	5	1630-1815	Yes	Yes	Yes	Yes	Research
124	7-18	1.0			Yes	Yes			Calibrate Pressure Instruments at Laramie
125	7-21	1.9	5	1540-1730	Yes	Yes	Yes	Yes	Research
126	7-22	2.2	4	1530-1740	Yes	Yes	Yes	Yes	Research
127	7-23	1.8	5	1430-1620	Yes	Yes	Yes	Yes	Research
128	7-29	2.1			Yes	Yes	Yes	Yes	Tower fly by
129	7-30	1.6	5	1745-1920	Yes	Yes	Yes	Yes	Research
130	7-31	1.6	5	1500-1635	Yes	Yes	Yes	Yes	Research
131	8-1	1.9			Yes	Yes	Yes	Yes	Aircraft track system calibration
132	8-1	1.7							Ferry A/C to Rapid City

Totals

Total Number of Flights	32
Total Aircraft Hours	48.4
Total Number of Cloud Penetrations	48

3. INSTRUMENT DEVELOPMENT SUMMARY

The 1975 field season was devoted largely to testing a number of new instruments. The results of the tests will be described in general terms, including recommendations for future development or testing where appropriate. The quality of the data produced by some of the instruments may, following more detailed inspection of the data, be found to differ from that described here.

3.1 Recording System

A new Precision Instruments data recorder and a Monitor Labs multiplexer were purchased prior to the field season to improve the reliability of data recording. The system was adapted to the T-28 and installed well before the season began and functioned reliably during the field season. Some grounding problems caused difficulties in recording accurate data in 1975. These problems introduced a bias in all channels which is different in the record and the monitor modes and seemed to change with the addition of some of the instruments prior to the beginning of the season. The system did appear to remain stable during the season so there should be little problem in putting a bias correction into the software.

Additional work is required on this system prior to the next field season to eliminate the bias and other minor problems.

3.2 Knollenberg Probes

A Knollenberg system was installed and worked admirably during the summer season. There were some problems but most of them were minor. The FSSP-100 and the 2-D probe complete with mounting structure are depicted in Fig. 1.

The data rate selector which controlled the rate at which the 2-D system recorded data was an intermittent problem. The result was that the tape was occasionally filled prior to the time an interesting cloud area was penetrated. This problem was compounded by the fact that there was no way to determine how much tape had been used since the indicator system in the cockpit never did work properly. The tape was often used considerably faster than desired and this fact went undetected until after the mission.

Problems were encountered with shedding of water from the nose of the 2-D probe, causing some elongated images in the data. The elongated images are obvious in the visual analysis of the data. The shedding problem was eased considerably with the addition of washers on the

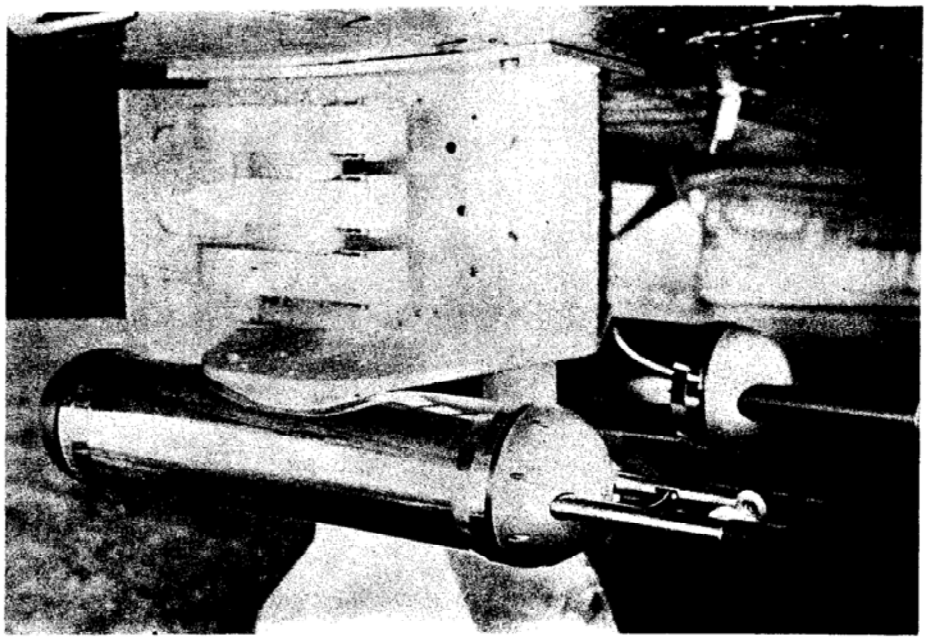

Fig. 1. Right wing pylon including the Knollenberg 2-D probe and the FSSP-100 probe, the foil impactor, and the mousetraps.

probe heads to direct the shed water away from the sample volume. This work was done by the University of Wyoming and their invention worked very well.

Minor electronic problems were encountered but were repaired very soon after they were detected by Particle Measuring Systems' technicians or Jim Weber of the NHRE staff.

The FSSP-100 probe worked well the entire summer with no problems worth comment.

The inability to distinguish between water and ice particles in the 2-D data is very disappointing, but extremely valuable and interesting data are produced by the 2-D probe and the entire Knollenberg system should become a permanent part of the T-28 system.

3.3 Laser Hail Sensor

The hail sensor (Fig. 2) was completed and installed only after the season was well under way. It was definitely a test year for this device since the laser hail sensor is an entirely new instrument. In

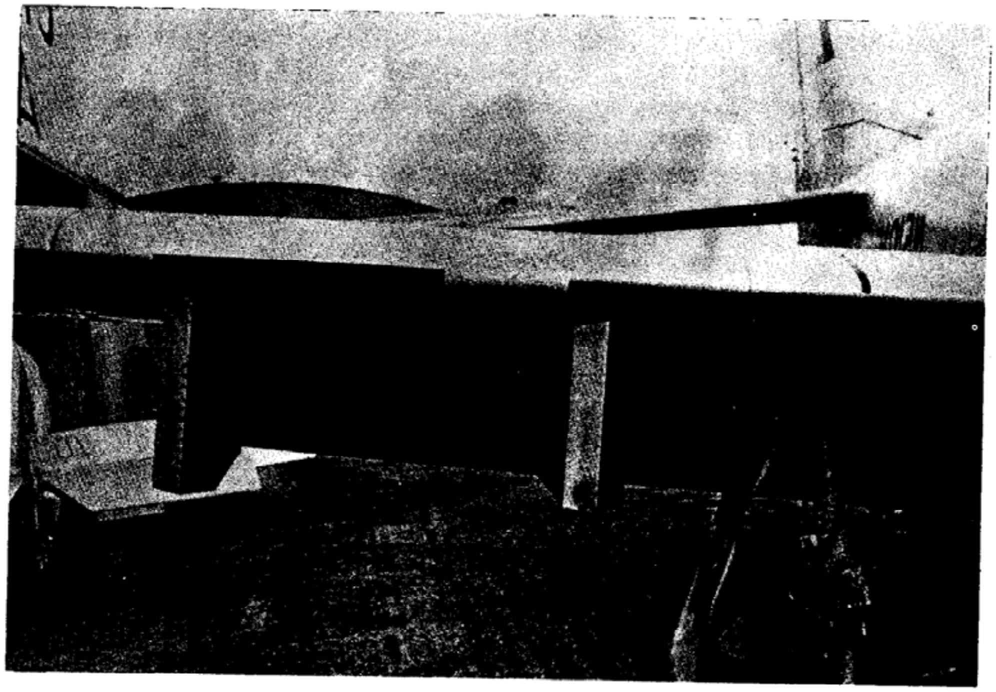

Fig. 2. The laser hail sensor mounted under the left wing.

general, the hail sensor had a successful season. The instrument flew on five of nine research flights and produced reasonable data on one flight. A number of growing pains were encountered with the hail sensor but the design seems sound and the instrument shows enough promise to justify continued development and use in future seasons.

3.4 Cannon Camera

The Cannon camera was the greatest disappointment of the summer. The system came in over weight and therefore could not be tested on the airplane during cloud penetrations. It was decided not to put the airplane down for the three to six days required for installation. The decision included a plan for installation and test after the regular season in an attempt to get proof of concept on the T-28. The concept has enough promise for phase identification to justify continued effort after the season.

3.5 Rosemount Static Pressure Transducer

The Rosemount static pressure transducer arrived in early June and was promptly installed on the aircraft. It is a standard instrument and functioned perfectly throughout the season. The only problem is that it came with a 0 - 5 volt output, thus restricting the resolution of the data since the recording system is set up to record ±5 volts. This restriction gives a resolution of only 1 mb in the pressure data, which is not as precise as desired. The solution is either to change the output of the transducer or change the input range of the recording system to accommodate the transducer.

3.6 Rosemount Differential Pressure Transducer

This instrument has the same problems though not as severe as the Rosemount static pressure transducer and the same solutions apply. The data currently has a resolution of 0.5 kt. No problems were experienced during the summer.

3.7 Reverse Flow Temperature

The reverse flow temperature measuring concept is assumed to be one of the best techniques for measuring temperature in clouds with the T-28. The NCAR reverse flow instrument had growing pains during the season. The sensor started out with an NCAR developed reverse flow housing (Fig. 3) and a Minco platinum resistance element with

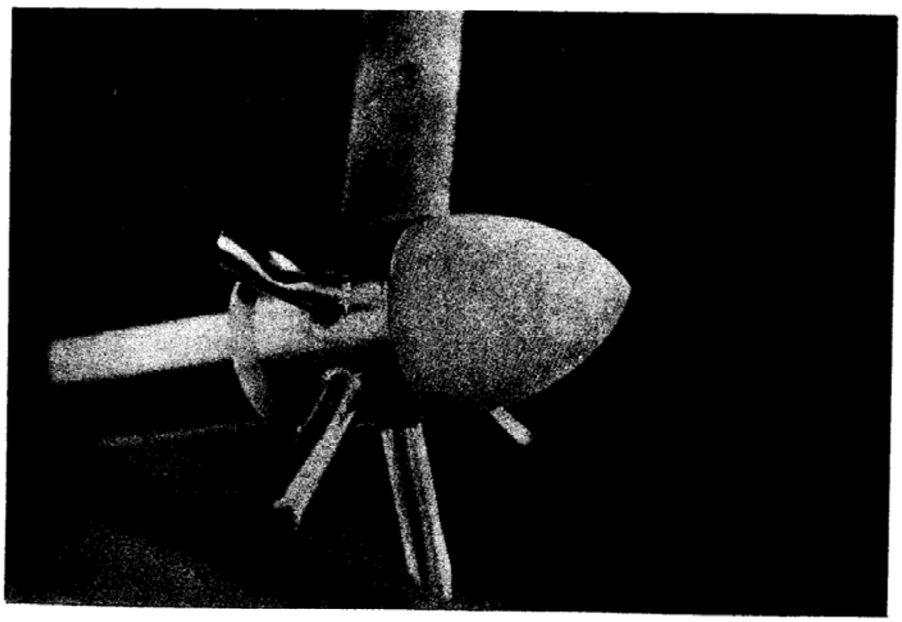

Fig. 3. The NCAR reverse flow temperature sensor housing with some hail damage.

an NCAR built electronics package. The platinum element with its 1 mil wire was not durable enough to stand up under the severe shock and vibration environment on the T-28 wing tip. The element was replaced with a diode and a matched electronics package from the NOAA/NCAR sailplane. The reverse flow housing was retained. This modification worked admirably during the season and should be retained for future seasons.

3.8 Rosemount Temperature

The Rosemount temperature sensor is not new to the T-28 package but enough work was done on it to be worthy of discussion. The unit has given immeasurable trouble and has never produced reliable data. Early in the season it was discovered that the electronics used with the system were not designed for use on an airplane (explaining many of the previous problems). About mid season the old electronics package from the platinum resistance element reverse flow system was adapted to the Rosemount sensor. This combination seemed to work reasonably well for the remainder of the season. The Rosemount deiced temperature system is standard enough that one should be carried on the T-28 even though the system is subject to icing in severe environments. It is therefore suggested that this instrument be replaced with a standard Rosemount package with electronics appropriate for aircraft use.

3.9 Vertical Accelerometer

A Humphrey vertically stabilized accelerometer was purchased and installed prior to the 1975 field season. In addition to accelerations, the instrument produces pitch and roll signals. The pitch and roll system worked with no problems for the entire summer but the accelerometer portion of the instrument failed prior to Flight 120. We felt that it was better to continue to get pitch and roll signals than to send the instrument to the factory for repair and lose all the data from it. The instrument needs to be repaired prior to next field season in order to provide good data on turbulence and shear zones.

3.10 Peak Accelerations

A device was designed and built by engineers at IAS to detect the peak accelerations encountered each second in both the positive and negative directions and hold these values for recording once each second. The device was to get its information from the Humphrey accelerometer but since the latter failed prior to the installation of this device, we did not get a test on the peak acceleration system. Continued development of the device is recommended.

3.11 Heading

A synchro-to-DC converter was designed and built by IAS engineers to enable recording of the heading from the compass system on the aircraft. The device seemed to work as designed. This variable should continue to be recorded for use in wind field calculations.

3.12 Second DME

A second DME was installed in the T-28. The combination of two DME's and the VOR is used as a back-up source of aircraft track information, with the M-33 radar as the primary system. This system worked with no problems until Flight 129 when the second DME failed. We were unable to get it repaired prior to the end of the season. The VOR/DME system is not as accurate for aircraft location as the M-33 but it should continue to be used as a back-up.

3.13 True Airspeed

A true airspeed computer was designed and built by NCAR personnel to drive the clock on the Knollenberg probes and the rotating mirrors on the Cannon camera. The output was also recorded. The device worked with no problems.

3.14 High Resolution Pressure

Because of the limited resolution of the static pressure transducer output and the desire to look for small scale pressure perturbations and differentiate the pressure to obtain vertical velocity it was decided to build a "times ten" amplifier for the static pressure transducer. The device was designed and built by IAS engineers and gave every indication of working correctly during the season.

3.15 Telemetry

Testing of a telemetry system was planned on a limited, time permitting basis during the 1975 season. This work, however, was accelerated considerably following the forced deletion of the back-up onboard recorder. A telemetry system was hastily developed as a back-up system to telemeter voice and sixteen channels of selected data to the Cheyenne office in real time. The voice portion of the system worked with no problems all summer but a valid check of the data channels was never accomplished due to problems with the telephone link to the computer in Rapid City.

Since the primary data system functioned reliably, we were not forced to use the telemetry. However, it gave every indication of working properly. If the telemetry system is to be used as a back-up for the primary data system, it requires considerable development since at present there is no time signal with the data and the system is limited to sixteen channels.

3.16 Quick Recall

The quick recall system as originally conceived could not be used since we were forced to eliminate the secondary recorder onboard the aircraft that was to be the source of quick recall data. The next plan was to send the telemetered data over phone lines to the computer at Rapid City for a quick check of data quality. Analog traces of the data were then to be returned to Cheyenne via telecopier. Because of the phone line problem noted in Section 3.15, this was never done. Instead the data tapes from the primary system were shipped on the bus to Rapid City on an overnight basis. The tapes were processed the following morning and the analog traces transmitted back to Cheyenne via telecopier for a quality check (Fig. 4). This system was acceptable (no tapes were lost enroute). In fact, this procedure proved somewhat more useful than that originally planned, since all the data could be checked instead of only the sixteen channels on the telemetry system. The returned data could also be used for limited data analysis since it had time data that were absent from the telemetry data.

A quick recall system is needed and this system could use substantial improvement prior to the next field season.

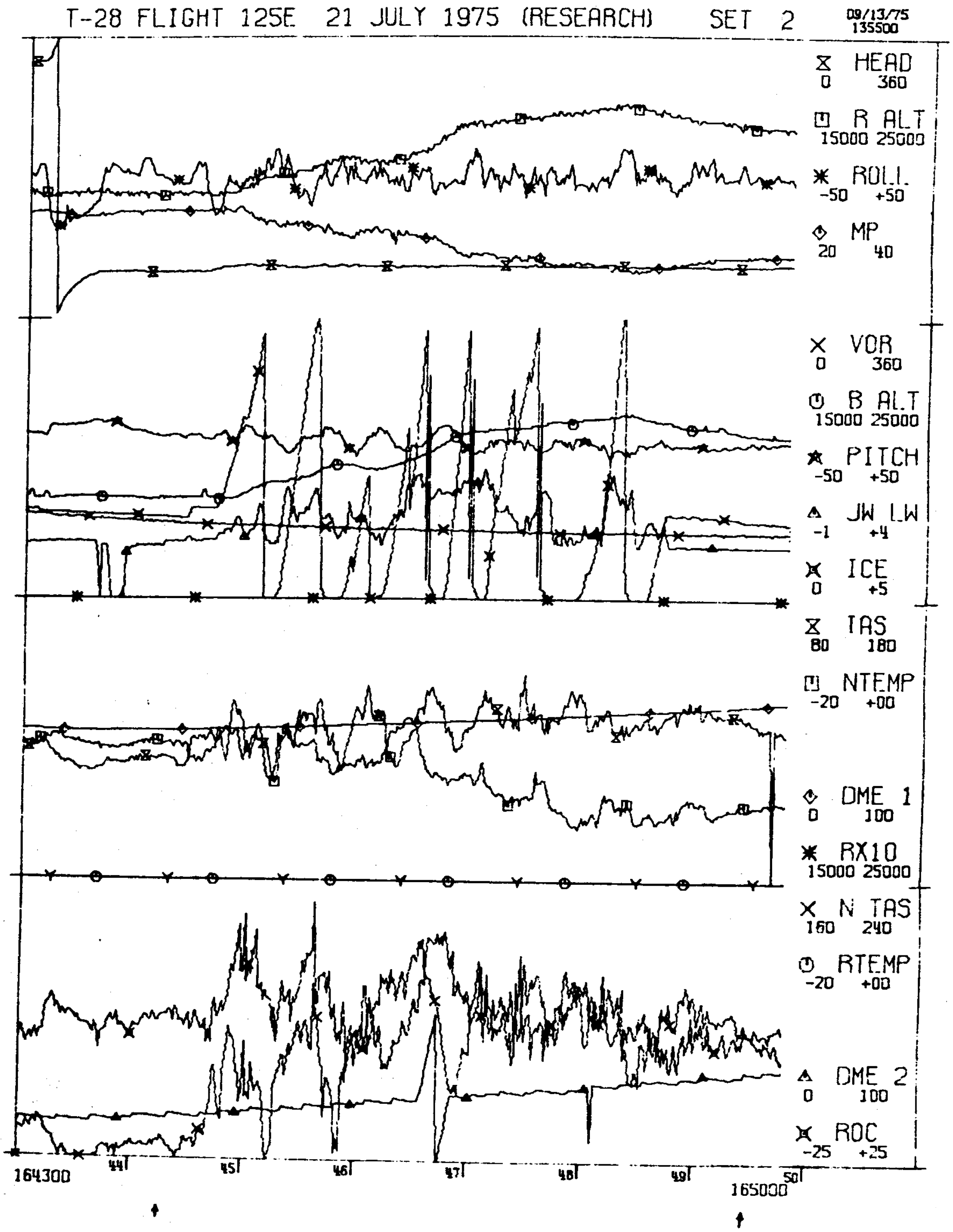

Fig. 4. Quick recall data as transmitted from Rapid City to Cheyenne over a telecopier. Data is from Penetration 5 on 21 July 1975.

4. RESEARCH ACCOMPLISHED

The successful accomplishment of any research during the 1975 field season was dependent on the functioning of the new instruments and the availability of suitable weather. The instrumentation worked reasonably well, as described in Section 3, and according to Table 1 enough suitable weather was present to test the equipment and get some valuable research data.

The cloud penetration plan was to attempt penetrations in the manner depicted in Figs. 5 and 6. The purpose of this plan was to look into the nature of the WER (weak echo region), the EC (embryo curtain) and the FE (first echo) region. A summary of impressions of the operational days during 1975 made by the project meteorologist at Grover is provided in Appendix A. At this time specific results are not available since the data have not been analyzed in detail, but some general observations and a summary of the data available are provided in the following sections.

No clouds were seeded during the 1975 season so no seeded clouds were available for observation. Therefore, all studies of seeding effects (Objective 3 in Section 1) are restricted to data from previous seasons and no mention of that work will be made in this report.

4.1 Concentrations of Large Particles

The foil impactor, Knollenberg 2-D probe, and Cannon camera were to gather data on this subject. The data from the 2-D probe and the foil impactor are of good quality so some results should be available following detailed data analysis. Good quantitative data on large particles are available. Following reduction of the foil data, the 2-D data, and the radar data, they can be put in the proper time-space location to draw conclusions.

4.2 Phases of Large Particles

A combination of pilot's comments, Knollenberg 2-D probe, Cannon camera, and foil impactor data were expected to establish the phases of the particles encountered in these various parts of the thunderstorm. The Cannon camera, of course, was not carried this season. The Knollenberg 2-D probe proved unable to furnish unambiguous information as to the phases of the particles. The foil impactor data are sufficiently ambiguous to cast some doubt on the interpretation of the results. The pilot's impressions are subject to some question also, even though he has the impression of large quantities of mostly liquid

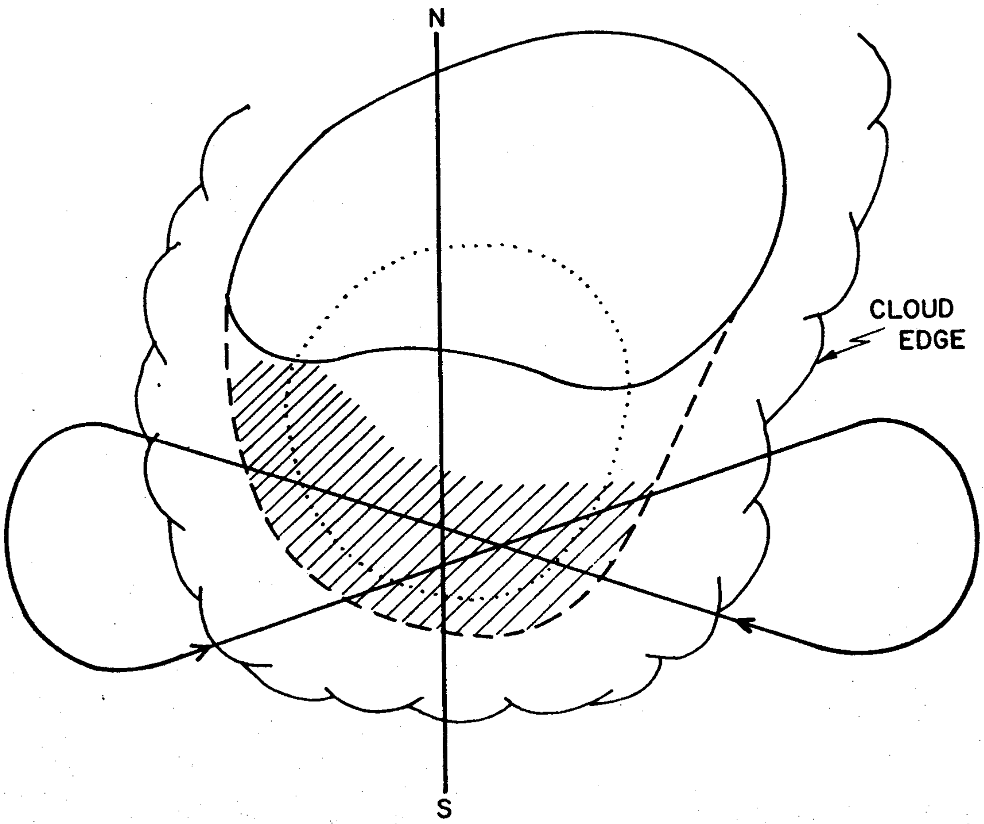

Fig. 5. Schematic plan view of a cloud showing the planned penetration track of the T-28. The dotted line encloses the extent of the updraft and the solid line shows the radar echo at penetration level. The dashed line shows the extent of the intense echo at some level above flight altitude (i.e., above weak echo region). The hatched region shows the region of interest for the penetrations.

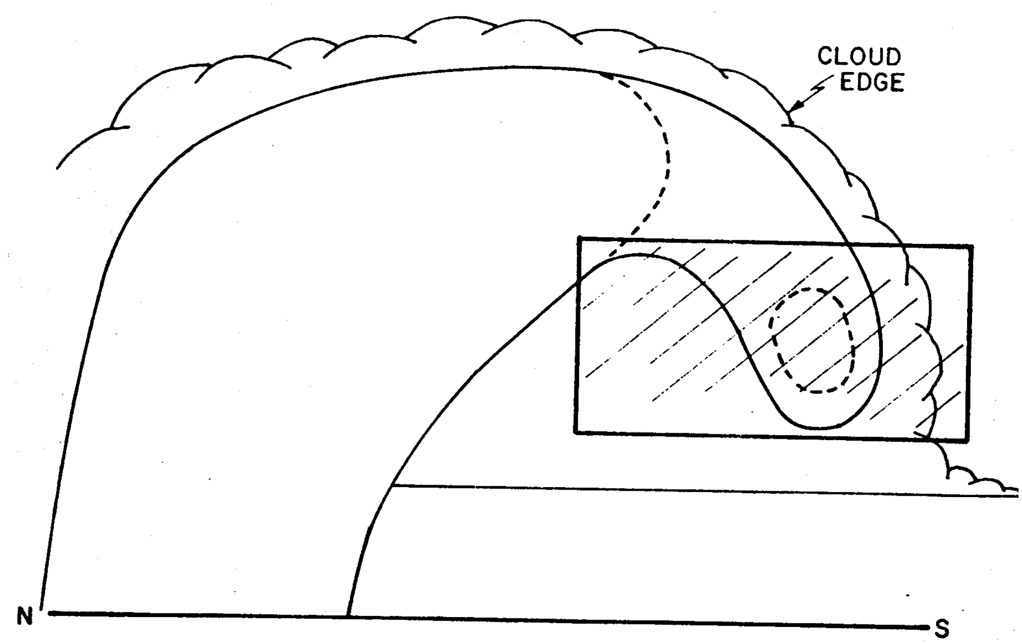

Fig. 6. Vertical section along line N-S in Fig. 5. The hatched region shows the region of interest for the T-28 penetrations. If the storm is a supercell type, the overhang region represents the embryo curtain. If the storm is a multicell type, the dashed lines denote the radar echo, with the dashed line inside the region of interest illustrating first echo formation in a new cell.

particles present. The phase question will not be unambiguously answered from the data gathered during the 1975 summer season, but the data should provide some additional insight into the problem. The addition of the Cannon camera in subsequent seasons should enable the distinction to be made more positively.

4.3 Cloud Water Concentrations

The Knollenberg FSSP-100 probe and the Johnson-Williams liquid water content probe were to have gathered data on the location and quantity of this very important hail growth material. Both of these pieces of equipment worked very well during the entire season, providing good data, and at first glance seemed to agree well with each other. The greatest abundance of cloud water is found in the active updraft portions of the cloud as has been previously reported (Sand *et al.*, 1974a). The combination of the data from the two probes will enable a more quantitative appraisal of the total cloud water present, and the FSSP-100 probe will provide size spectra of the droplets present up to 30 μm.

4.4 Turbulence Spectra

Data on the turbulence spectra inside thunderstorms were to be gathered with the Humphrey accelerometer and the Rosemount differential pressure transducer (airspeed fluctuations). Since the Humphrey accelerometer failed early in the season, these data will be unavailable but the airspeed transducer worked quite well during the entire season. A program already exists to analyze the data to obtain turbulence spectra, and some of this analysis should be done this winter.

4.5 Aerosol Distributions

Analysis of the samples from the "mousetrap" was to have provided information on the presence of large aerosols (on the order of 60 μm diameter). The "mousetraps" did not have a successful flight this past season so no data is available.

4.6 Composition of the High Reflectivity Zones

Previous work (Sand *et al.*, 1974b) has shown that the high reflectivity zones are composed primarily of ice particles. The addition of the hail sensor to the T-28 system in 1975 was seen as a means of providing more quantitative data about the composition of the high reflectivity zones. The Knollenberg 2-D probe and the foil impactor were expected to provide supporting data for this study. The combination of these quantitative data was seen as a good check on the DURAD system for hail detection. Things such as the threshold of detection, effects of various drop size spectra and wet and dry particles on reflectivity factors, the actual presence of hail, and the presence or absence of rain mixed with hail were also seen as potential studies that could be done with the equipment carried on the T-28 and the Grover radar data.

Primary research effort was devoted to penetrations of the weak echo region and the embryo curtain during the season, so few penetrations of the high reflectivity zones were made. Those that were made should provide the necessary basis for a start on the above studies. Hail sensor data appear valid for only one flight during the season so this will restrict the amount of data available for the above studies.

5. OPERATIONAL CONSIDERATIONS

The outstanding cooperation of all NHRE personnel prior to and during the season was an invaluable aid in the smooth operation of the summer season. From the point of view of the South Dakota School of Mines and Technology, NHRE is working as a successful team effort.

Basing the T-28 out of Cheyenne still appears to be quite desirable, although Cheyenne does have shortcomings that could be overcome. The electrical power available there is less than desired in quality and quantity; the building used as an office and lab is very old and has only a two wire system. A better electrical system should be installed at the Cheyenne facility to improve our capability and the safety of operations there. There are no available hangars on the field and all aircraft work must be done outside on the ramp. According to the operator at Cheyenne, there is a good chance that there will be hangar space available next year. With the high cost equipment currently installed on the T-28, the availability of hangar space could become a dominant consideration.

The base radio facility at Cheyenne proved extremely helpful in many cases. The daily weather briefing over this system with frequent updates on the weather and T-28 status were most helpful.

The radar control and tracking system worked very well during the season. The absence of the FAA controllers at Grover produced confusion occasionally since the Grover site had no idea when the FAA ARTCC was talking to the airplane or vice versa. This minor problem can easily be resolved by replacement of the FAA personnel at Grover. The extreme air traffic congestion along the southeast edge of the area was at times a source of some confusion, with no direct FAA contact at Grover. With the ever present congestion along this edge of the area it would be a good procedure to avoid operations there whenever possible.

The radar data playback, complete with aircraft track, through the DADS system proved very useful during the summer and should routinely be used as a learning tool during the season.

6. CONCLUSIONS

The season produced considerably more weather than was expected and there were plenty of opportunities to test instruments and gather scientific data. With the exception of the "mousetraps" and the Humphrey accelerometer, the new equipment worked well during the season. The Cannon camera was not installed due to problems with the weight of the instrument.

The data gathered should provide some valuable insight into the composition of the weak echo region and the embryo curtain. The ice/water distinction is not as obvious as had been hoped prior to the beginning of the season.

The failure of the Humphrey accelerometer early in the season was a dissapointment but the good indicated airspeed data should provide some information on turbulence.

Operationally the season went well with only minor aircraft problems and good cooperation from the FAA. The Grover radar site provided good support and all indications at this point are that the data from the radar site and the T-28 should be very good.

ACKNOWLEDGMENT

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APPENDIX A

SUMMARY OF NHRE OPERATIONAL DAYS - 1975

General Comments

Penetrations were made on nine days during the season. The storms fall into two rough caregories on the basis of observations made at the times of the flights. These were: moderate storms, which occurred on 16, 21, 22, 23, and 31 July and produced hail ranging in size from pea to roughly one inch in diameter; and weak storms, which occurred on 7, 14, 15, and 30 July and had no known hail. In fact, it would be difficult to classify some of the latter storms as thunderstorms.

All of the hailstorms were judged to be of the multicell variety. One of the storms (21 July) appeared to take on quasi-steady characteristics for about a one hour period during its lifetime.

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

1. 22 July
2. 21 July
3. 16 July
4. 23 July
5. 31 July
6. 14 July
7. 15 July
8. 7 July
9. 30 July

7 July - Very weak storms in area, but reflectivity factors seemed unusually high. First operational day of season, some confusion experienced in interpreting radar displays. Penetrations were difficult to coordinate because storms lacked organization and we tended to be cautious because of the high reported reflectivities. No hail encountered and none occurred at ground.

14 July - Storms were difficult to work because they were weak and had relatively short lifetimes with lack of organization. This day was only slightly better than 7 July in terms of storm quality but penetration coordination significantly better. No hail.

15 July - Rather weak clouds which formed and dissipated rapidly. First two penetrations were in a dissipating storm. Later penetrations got fairly good icing but clouds were still weak and lacked organization. Storm quality about the same as 7 and 14 July with penetration quality similar to 14 July.

16 July - Excellent day. Penetrations 1 and 2 were in hail formation region on south and southeast side of echo in new growth. Penetration 3 was in cell which eventually produced hail at the Grover site.

21 July - Another excellent day. Two of the penetrations were in the overhang region, while two were in developing feeder clouds further from the main echo. Overhang penetrations were within about 2 nm of maximum reflectivity factor at flight altitude (about 50 dBz). Storm seemed quite steady during the last hour of its lifetime.

22 July - Probably the best day of the season. Two penetrations were in feeders, while another was in overhang region. Accumulation of about 2 in (5 cm) ice during the latter penetration. Only three penetrations were possible because of the heavy icing. Near hook cloud on DRI scope at about 1646 MDT.

23 July - Only rapidly moving storm of season. Remarkably persistent with new cells appearing on southwest side. Penetrations were made visually at first in newly developing clouds and later were vectored from GRO as cells merged or became mature storms on their own. An excellent storm worthy of study but takeoff alert was probably half hour late for optimum work on this storm.

30 July - Echoes moved into area from the south and were in a dissipating stage. Penetrations were in extremely weak cells with little organization. Aircraft encountered nearly all ice particles although no hail was encountered in air or on ground despite 60+ dBz values below flight altitude. The decaying state of these storms and their general weakness make this the poorest case of the year. Penetrations were like trying to chase ghosts as they tended to disappear when the aircraft approached.

31 July - Good penetrations in a storm which fed on southwest and south side. First two penetrations were near max dBz in a mature cell and the last two were in younger cells which were merging with main cell. This storm was not quite as persistent as those occurring on 16, 21, 22, and 23 July but, nevertheless, it was a good case.