Report 70-13

November 1970

REPORT ON OPERATION OF T-28 ARMORED AIRCRAFT WITH JOINT HAIL RESEARCH PROJECT AT GREELEY, COLORADO 21 JULY - 1 AUGUST 1970

By: R. Richard A. Schleusener, J. H. Hirsch, and L. B. Youngren

Prepared for:

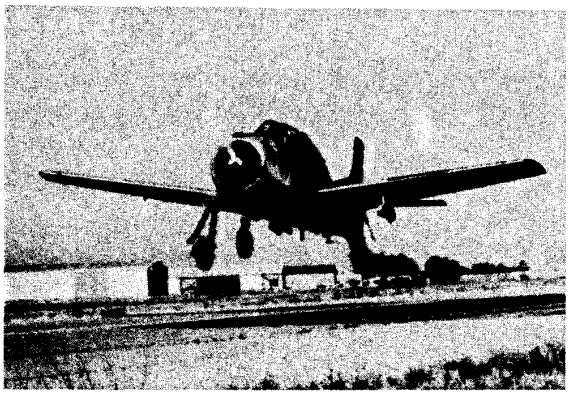
National Science Foundation
Washington, D. C. 20550

NSF Grant GA-24651

Institute of Atmospheric Sciences

South Dakota School of Mines and Technology

Rapid City, South Dakota 57701



T-28 taking off from Weld County Airport, Colorado

ABSTRACT

A T-28 aircraft that had been armored to withstand hailstone impacts and that was equipped with meteorological sensors was operated from Weld County Airport, Colorado from 21 July to 1 August 1970 in cooperation with the Joint Hail Research Project (JHRP).

To gain experience in operation of the aircraft, it was first flown into smaller "feeder" clouds, then into increasingly severe storms. By the end of the season, penetrations had been made through storms with measured radar reflectivities greater than 60 dBz.

Total flight time in Colorado was 25.6 hours. Meteorological data were collected on four separate research missions which included 15 cloud penetrations.

Calibration data on pressure and temperature sensors which were obtained in cooperation with the NCAR flight facility at Jefferson County Airport are presented.

Work is continuing to further develop the instrumentation on the T-28 and to analyze the data collected.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1. INTRODUCTION

This is a report of work accomplished in the operation of the T-28 armored aircraft with the Joint Hail Research Project at Greeley, Colorado during the period 21 July - 1 August 1970.

The T-28 aircraft had been procured and armor plated for hailstorm penetration by a commercial firm under previous grants to the Institute from the National Science Foundation. The aircraft was delivered to the Institute in January 1970, and additional modifications to the airframe and meteorological instrumentation were accomplished during the spring and summer of 1970 prior to the use of the aircraft in Greeley in July and August 1970.

Use of the aircraft in conjunction with the Joint Hail Research Project provided valuable experience in actual field use of the aircraft in connection with the other Joint Hail Research Project activities. The aircraft was used for making penetrations in a limited number of clouds, beginning with smaller "feeder" clouds and continuing with penetrations through increasingly severe storms. At the end of the season, penetrations had been made through storms with measured reflectivities greater than 60 dBz.

This report provides a summary of the work done in operation of the airplane in connection with the Joint Hail Research Project. Work is continuing to further develop the instrumentation and to analyze the data collected.

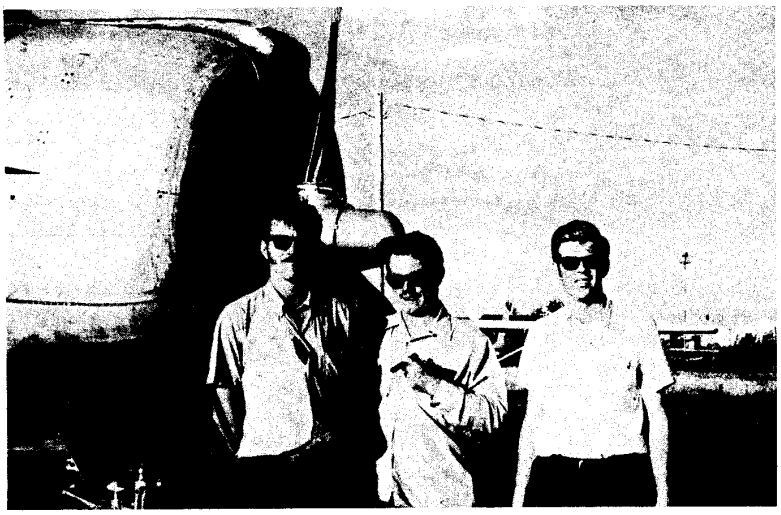


Fig. 1. Personnel of the project at Weld County Airport, July 1970. Left to right: Kenneth R. Jasper, L. B. Youngren, and John H. Hirsch. (Not shown: R. A. Schleusener and W. G. Myers)

Fig. 2. T-28 running up engine on ramp at Weld County Airport, July 1970. FPS-6 of Greeley radar complex shows in left background.

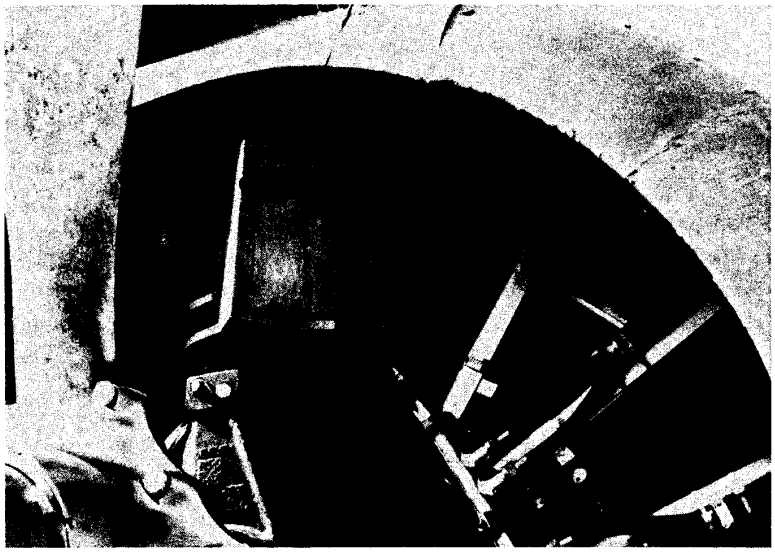


Fig. 3. View of devices for protection of elements of T-28 engine from hail damage. Top center shows heavy aluminum shield used to protect the propeller governor. Metal clamps fasten protective metal over push rod covers.

2. THE AIRCRAFT

The T-28 was based at Weld County Airport, Greeley, Colorado during the period 21 July through 1 August 1970. Sixteen flights were flown during which 25.6 hours were logged.

Three research missions were flown for a total of 6.8 hours. Five flights were for ferry purposes amounting to 6.6 hours. There were four test flights during which 4.9 hours were flown. Calibration and instrumentation testing were accomplished during the remaining four flights and 7.3 hours.

Table 1 presents a chronology of the T-28 flights.

The airplane was equipped with the following navigational and communications electronics:

(1) 3 Mark XII radios

(2) DME

(3) "X" band transponder

(4) "S" band transponder

(5) ADF

(6) Intercom system

(7) Two voice recorders.

One voice recorder was used to record pilot's comments on cloud penetrations. The second recorded hail impact noise. The parameters recorded by the pilot on the first recorder during penetrations were: (1) times of starting/ending penetration, (2) altitudes at start/end of penetration, and (3) headings at start/end of penetration, plus remarks on hail, structural icing, rain, turbulence, and other remarks deemed pertinent.

The second recorder was connected to a geophone located inside the cockpit at the base of the wind screen. It recorded the noise level of hailstones impacting against the windscreen.

TABLE 1

Summary of T-28 Flights in Colorado, July - August 1970

Date	Flight No.	Purpose	Takeoff (MDT)	Land (MDT)	Flight Hours	Accumulated Flt. Hours
21 July	1	Rapid City - Chadron: Ferry and calibration	0814	0938	1.4	1.4
21 July	2	Chadron - Loveland - 4GX: Ferry	1107	1249	1.7	3.1
21 July	3	4GX - local: Data pack test	1830	1942	1.2	4.3
22 July	4	4GX - local: Data pack test	1340	1552	2.2	6.5
22 July	5	4GX - local: Mission	1650	1756	1.1	7.6
22 July	6	4GX - Cheyenne: VOR fix (RON at Cheyenne)	1902	1946	.7	8.3
23 July	7	Cheyenne - 4GX: Ferry	0746	0828	.7	9.0
24 July	8	4GX - local: Communication and fuel pump test	1822	1958	1.6	10.6
25 July	9	4GX - local: Microphone test	1649	1710	1.6	12.2
27 July	10	4GX - Denver: Microphone fix and test	1050	1150	1.0	13.2
27 July	11	Denver - 4GX: Mission	1438	1744	3.1	16.3
28 July	12	4GX - local: Inverter test	1359	1441	.7	17.0
28 July	13	4GX - local: Mission	1603	1839	2.6	19.6
30 July	14	4GX - Jeffco - 4GX: Low-level calibration	0855	1107	2.2	21.8
30 July	15	4GX - local: High-level test	1134	1316	1.7	23.5
1 August	16	4GX - Rapid City: Ferry	1801	2007	2.1	25.6

Symbols: 4GX - Weld County Airport
RON - Remain overnight

3. THE DATA SYSTEM

The data system on the T-28 includes sensors to measure meteorological and aircraft parameters. These parameters are sampled and recorded at a rate of 2.4 records each second with each record containing twenty channels of input data from the various sensors.

3.1 Sensors

Parameters of particular interest were: altitude, airspeed, rate of climb, vertical acceleration, temperature, liquid water content, raindrop sizing, aircraft position, and time. These parameters are summarized in Table 2 with a brief description of each sensor.

3.2 Recording System

The data recording system on the aircraft is centered around a Metrodata Systems DL620A digital magnetic tape recorder. The system specifications are listed in Table 3. Meteorological and aircraft data in analog form were used as inputs to the recorder. These data were processed with a self-contained analog-to-digital converter and multiplexer, then recorded onto 1/4" four-track magnetic tape cartridges for computer reduction and analysis.

3.3 Data Reduction

Existing equipment was available to read the data from the DL620A. Computer programs were developed to transform the recorded voltages into engineering units. Additional programs were written to analyze the data and present it in a suitable form for the user.

Three specific requirements were attempted in the data analysis. A "quick turnaround" analysis was available on a 24-hour basis. These included cloud penetration information in analytical form. A sample is shown in Figure 4. The data were arranged by aircraft penetration and parameter. The maximum, minimum, and mean values of the parameters were also presented.

The second requirement in data reduction was to ascertain that the aircraft's instrumentation system was functioning correctly. Transparency photographs of a computer-generated display (similar to Fig. 4) of selected parameters were used for this purpose.

The third requirement for data reduction was for hard copy (teletype form paper) printout, in engineering units, of any or all of the data recorded by the instrumentation system for each second during the penetration of the aircraft.

TABLE 2

Airborne Meteorological Instrumentation on T-28

Parameter	Manufacturer	Range	Description
Altitude (Alt)	Ball EX-210-B	-200 to 30,000 ft	Pressure transducer
Airspeed (IAS)	CIC 7100	0 to 350 kts	Pressure transducer
Updraft Velocity (UVEL)	Ball 101-B	-3000 to +3000 ft min^{-1}	Electric variometer
Vertical acceleration	Stratham A-45	±15G	Accelerometer
Temperature (Temp)	WSI TV-26	-30 to +30C	Thermistor in reverse flow housing
Liquid Water Content (LWC)	J-W LWH	0 to 6 gm^{-3}	Hot wire resistance
Raindrop sizing	WSI RR-40	9 classes	Force transducer
Position	Acft Nav-aids	0-200 nm	VOR bearing and DME range
Time	Bulova	24 hr	Accutron clock

TABLE 3

Specifications of DL620A Digital Recorder

Data Input:	Analog (differential voltages) 1 meg Ω impedance
Number of channels:	18 (plus two time channels) Four reserved for RR40
Recording Rate:	Selectable Continuous (48 channels/sec) Intermittent 10-sec, 1-min, 10-min, 1 hr
Data Capacity:	Approx. 1800 20-channel records
Recording Time:	60 min/cartridge (continuous mode)
Standard Analog Input:	-5 to +5 VDC
Resolution:	1 part in 2000 (5 mv)
Power Requirements:	35 watts, 115 volts (50-400 Hz)
Environmental Temperature Range:	0 to 40C
Dimensions:	8.3 x 11.1 x 11.0 inches
Weight:	18 lbs (approx.)

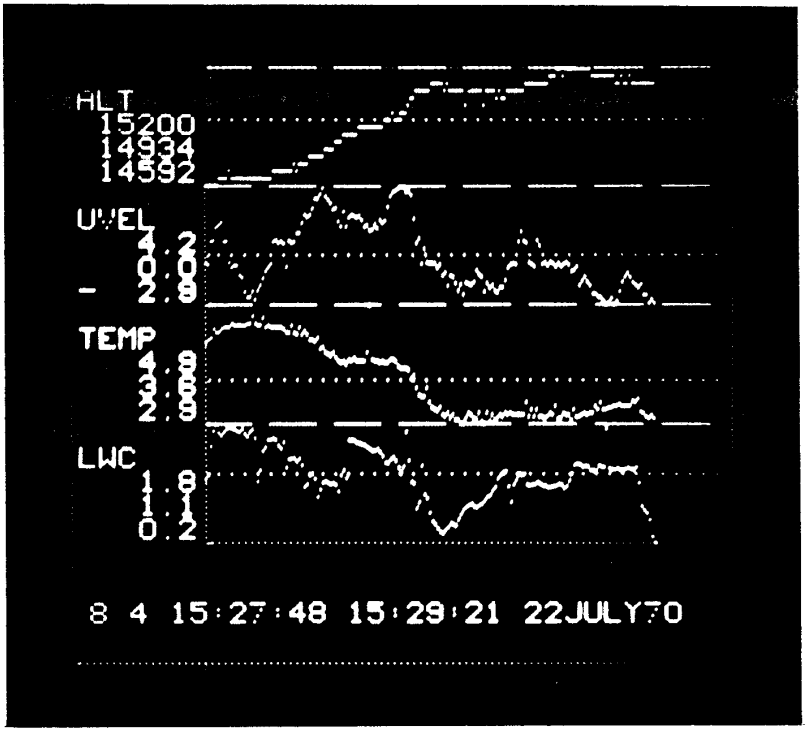


Fig. 4. Sample of computer generated display of T-28 penetration data. Traces show altitude in feet, updraft velocity in m sec^{-1}, temperature in °C, and liquid water content in gm^{-3} for a cloud penetration beginning 1527:48 hours and ending 1529:21 on July 22, 1970. Numbers at left show maximum, mean, and minimum values of each variable. Means are indicated on graphs by dotted lines.

4. SUMMARY OF DATA COLLECTED

The T-28 aircraft was based at Greeley, Colorado from 21 July to 1 August 1970. Four missions were flown during this period with one of the missions being a calibration flight at low levels at Jeffco Airport. Table 4 is a summary of usable data obtained from the sensors listed in Table 2 for the four missions. The table shows that fifteen cloud penetrations were made and that usable data was obtained from all but one mission. Appendix A contains daily activity logs of the personnel who participated in the Joint Hail Research Project. Appendix B gives the calibration procedures used in calibrating pressure and temperature sensors during the low-level flights on 30 July.

TABLE 4

T-28 Data Summary*

Date	Mission†	Number of Penetrations	Voice Tape	Alt	IAS	UVEL	Temp	LWC	Raindrop Sizing	Position	Time
7/22	1	1	0	X	X	X	X	X	0	X	X
7/27	1	7	X	X	X	X	X	0	0	X	X
7/28	1	7	X	Recorder in 1-min mode							
7/30	2	0	X	X	X	X	X	0	0	0	X

*Code:

X - Usable data collected
0 - No usable data collected

†Code:

1 - Cloud penetration
2 - Low-level calibration

5. IMPRESSIONS FROM EXPERIENCE TO DATE

The impression gained from use of the aircraft to date is that it can provide a satisfactory platform for making measurements in the interior and near environment of hailstorms. The current configuration of the aircraft and its present engine give an altitude capability such that the aircraft can be used satisfactorily up to altitudes of approximately 24,000 ft, which marks the upper limit of simplified air traffic control procedures. The combination of the upper limitation on altitude for the aircraft and the simplified air traffic control procedures below 24,000 ft make it appear desirable to utilize the T-28 for measurements at 24,000 ft and lower elevations.

The aircraft was used successfully in penetrating storms having measured reflectivities in excess of 60 dBz. Structural ice did accumulate during repeated passes of the aircraft during some penetrations, but has not been a major limitation during flights made to date.

During 1970, the first summer season of operation of the T-28, a variety of miscellaneous mechanical problems were encountered, typical in the operation of an aircraft that had not had the benefit of regular and routine use.

The armor which was applied for protection of the aircraft, both for the leading edges of the wing and tail surfaces and for the windshield, appears to be satisfactory to protect the plane against hail damage. Minor damage to running lights and to exposed portions of the wiring harness was encountered during one flight through moderate hail.

It was a source of satisfaction to have the instrumentation and data recording system work satisfactorily after a short time for preparation. The data recording system on the plane and its associated computer data analysis provides a mechanism for a fast turnaround of data for analysis, as well as for a check on the performance of individual sensors. The data recorded to date are largely qualitative in nature, but can be upgraded to permit increasingly quantitative measurements of the hailstorm updrafts and internal composition of hailstorms.

Experience from the operation in Colorado reinforces the idea that adequate mechanical maintenance facilities for the aircraft are essential. Adequate mechanical maintenance facilities did exist at one of the fixed base operations at Greeley. This provided substantial assistance in overcoming the various mechanical difficulties experienced with the airplane.

One of the limitations of the 1970 Joint Hail Research Project was the inability to separate the aircraft control function from the

meteorological information function. The dual role of the radars at Greeley in providing both aircraft operational control and meteorological information is considered an undesirable limitation for most effective project organization.

The absence of routine debriefing sessions was a serious limitation to the Joint Hail Research Project. A much higher degree of learning could be accomplished by introducing routine debriefing sessions after each operational day.

6. FUTURE PLANS

It is planned to continue with analysis of data collected in 1970 for the purpose of gaining more information on the characteristics of updrafts during the penetrations made, as well as the internal composition of the high reflectivity areas penetrated. In addition, the data will be analyzed from the point of view of developing appropriate procedures for data collection and analysis for future work. The aircraft meteorological instrumentation will be reworked to overcome difficulties encountered in the 1970 operation. For example, the location of several items of equipment in the cockpit will be revised to make it easier for pilot access, and the procedures for turning on and monitoring of meteorological equipment will be reviewed to simplify the pilot's tasks to the maximum extent possible.

Work will continue to develop the data collection and analysis procedures to permit a rapid reduction of data and its use in numerical models of hailstone and hailstorm growth.

APPENDIX A

DAILY ACTIVITY LOGS

21 July 1970

Personnel present: Schleusener, Myers, Youngren, Jasper

0814 - T-28 departed Rapid City. Myers and Jasper departed in Mooney aircraft. Schleusener departed Rapid City via School vehicle.

1530 - Conference with Northeast Colorado Hail Experiment personnel to review details of plans for operation of the T-28.

1830 - T-28 takeoff for local flight test.

1942 - T-28 landed.

22 July 1970

Personnel present: Schleusener, Myers, Youngren, Jasper

1340 - T-28 takeoff for dry run and communications check.

1552 - T-28 landed.

1650 - T-28 takeoff for mission on a major line of thunderstorms that was passing through the area. One penetration was accomplished successfully in a feeder cloud on the south end of a large active storm just east of Greeley. The major storm had tops in excess of 50,000 ft and reported reflectivities in excess of 50 dBz.

1756 - T-28 landed.

1902 - T-28 departed for Cheyenne for radio repairs.

1946 - T-28 RON at Cheyenne.

23 July 1970

Personnel present: Schleusener, Myers, Hirsch, Youngren, Jasper

0746 - T-28 departed Cheyenne for Greeley.

0828 - T-28 landed.

1020 - Forecast from JHRP: "Hail experiment go, cumulus experiment go."

1341 - Revised project status from JHRP: "Hail experiment no-go, cumulus experiment no-go."

24 July 1970

Personnel present: Schleusener, Myers, Hirsch, Youngren, Jasper

0900 - Aircraft out of service for modification of battery mounts and fuel pump exchange.

1000 - JHRP forecast was "Hail experiment no-go, cumulus experiment standby."

1402 - Revised JHRP status: "Hail experiment standby, cumulus experiment standby."

1800 - T-28 ready for test flight with new fuel pump installed and battery mounts relocated.

1822 - T-28 takeoff from Greeley for test flight.

1958 - T-28 landed.

25 July 1970

Personnel present: Schleusener, Myers, Hirsch, Youngren, Jasper

1000 - JHRP forecast: "Cumulus standby, hail standby."

1400 - Revised JHRP status: "Cumulus experiment go, hail experiment standby."

1410 - Revised JHRP status: "Standby one more hour."

1515 - Revised status from JHRP: "No-go."

1649 - T-28 takeoff for communications check.

1710 - T-28 landed Greeley.

1830 - Schleusener, Hirsch, and Myers depart Greeley for Rapid City.

26 July 1970

Personnel present: At Greeley: Youngren and Jasper
At Rapid City: Schleusener, Hirsch, and Myers

A no-go day today wherein Youngren and Jasper remained with the aircraft and Hirsch, Schleusener, and Myers worked out calibration figures at Rapid City for the various instruments on the T-28.

27 July 1970

Personnel present: Schleusener, Hirsch, Myers, Youngren, Jasper

0815 - Myers, Hirsch, and Schleusener arrive Greeley.

1030 - JHRP forecast: "Hail experiment standby, cumulus experiment possible go."

1050 - T-28 takeoff for Denver for radio repair.

1150 - T-28 landed Denver.

1320 - Revised JHRP status: "Hail experiment standby, cumulus experiment go."

1438 - T-28 takeoff from Denver for mission.

1500 - T-28 directed to vicinity of New Raymer to search for adequate penetration opportunities and was able to make seven separate cloud penetrations between 1620 and 1720 MDT. In addition, the T-28 made one pass through a moderate rain shower approximately 10 miles south of Greeley for the purpose of testing the rain rate sensor. The flight was made at an altitude of approximately 8,000 ft.

1744 - T-28 landed in Greeley.

28 July 1970

Personnel present: Schleusener, Hirsch, Myers, Youngren, Jasper

0900 - Myers departed Greeley.

1030 - JHRP forecast: "Hail experiment go, cumulus experiment go."

1359 - T-28 takeoff for test.

1441 - T-28 landed.

1445 - Revised JHRP status: "Hail experiment standby, cumulus experiment go."

1603 - T-28 takeoff from Greeley for mission. Seven cloud penetrations were made on the hail case northeast of Greeley. Maximum radar top 47,000 ft; maximum reported reflectivity 66 dBz.

1839 - T-28 landed.

1852 - It was discovered that the DL620 tape recorder was on one-minute mode so only limited data were recovered from today's mission.

29 July 1970

Personnel present: Schleusener, Hirsch, Youngren, Jasper

1000 - JHRP forecast: "Hail experiment standby, cumulus experiment standby."

1350 - Revised JHRP status: "Hail experiment no-go, cumulus experiment standby."

1500 - Revised JHRP status: "No-go." No missions were flown this day.

30 July 1970

Personnel present: Schleusener, Hirsch, Youngren, Jasper

0855 - T-28 takeoff for Jeffco mission: low-level calibration flights. During the period 0900 hours to 1100 hours the T-28 made 12 runs for the purposes of calibrating temperature and pressure sensors at Jeffco Airport. Aircraft passes Nos. 4, 6, 9, and 11 were reported good with respect to aircraft position. These data are reduced and presented in Appendix B.

1107 - T-28 landed at Greeley.

1134 - T-28 takeoff for high-level calibration runs in order to determine aircraft performance at high altitudes. From the period 1207 to 1300 the aircraft made several high-altitude runs with various power settings to determine rate of climb characteristics.

1316 - T-28 landed.

1330 - Schleusener departed for Rapid City.

1345 - JHRP forecast: "Hail experiment no-go, cumulus experiment standby."

1710 - Revised JHRP status: "No-go for remainder of afternoon."

31 July 1970

Personnel present: Hirsch, Youngren, and Jasper

1045 - JHRP forecast: "Hail experiment no-go, cumulus experiment standby."

1345 - Revised JHRP status: "Cumulus experiment standby for one hour."

1400 - Revised JHRP status: "No-go." No mission flown this day.

1 August 1970

Personnel present: Hirsch, Youngren, and Jasper

1030 - JHRP forecast: "Hail experiment standby, cumulus experiment standby."

1330 - Revised JHRP status: "Standby until 1700."

1700 - Revised JHRP status: "No-go."

1801 - T-28 takeoff for Rapid City.

2007 - T-28 landed Rapid City.

APPENDIX B

CALIBRATION PROCEDURES FOR LOW-LEVEL FLY-BYS

Low-level fly-by missions were flown on 30 July at Jeffco Airport. The objectives of the flights were to:

1) Calibrate temperature sensors with a standard established by NCAR flight facility.

2) Calibrate pressure sensors with a standard established by NCAR flight facility.

Temperature

Air temperature is sensed by a Weather Science, Inc. TS-22 temperature system. A thermistor is enclosed within a reverse flow housing to reduce dynamic heating effects due to the speed of the aircraft. Output voltages of the system are linear throughout the temperature range -30C to +30C with an overall accuracy of ±0.2C. Data are recorded on the DL620A in an uncorrected value for temperature. This converted temperature is then corrected for dynamic heating by the equation:

$$T_c = T \dot{-} (2.5 \times 10^{-2} IAS) \qquad (1)$$

where T_c = corrected temperature (°C)

T = converted temperature from the DL620A reading

IAS = converted indicated airspeed from the DL620A

Pressure

Atmospheric pressure is measured with a Ball EX-210-B pressure transducer. Output voltages of the transducer system is linear throughout the range 10 to 30 inches of mercury, with an overall accuracy of ±0.02" Hg. Data are recorded on the DL620A in parts of one thousand and the following conversion equation is used to obtain pressure:

$$P = 30.2 - 0.02\ P_v \qquad (2)$$

where P = atmospheric pressure (inches Hg)

P_v = DL620A voltage

Pressure Altitude

Pressure altitude is obtained from the above pressure, sea-level altimeter setting 29.92, and a form of the hypsometric equation. The final equation to obtain the pressure altitude is

$$P.A. = \frac{T_0}{\Gamma}\left[1 - \left(\frac{P}{P_0}\right)^{\frac{\Gamma R}{g}}\right] \qquad (3)$$

where P.A. = pressure altitude

T_0 = standard sea level temperature

Γ = standard temperature lapse rate

P = atmospheric pressure

P_0 = standard sea level pressure

R = gas constant for dry air

g = acceleration due to gravity

Table 5 lists the results of the tower fly-bys on 30 July 1970 using Equations (1), (2), and (3) for passes No. 4, 6, 9, and 11. Pass definition numbers are taken from Brown (1970).[1]

---

[1]Brown, E. N., 1970: Test results of tower fly-bys. JHRP Report, 16 pp.

TABLE 5

Calibration Data from Jeffco Calibration Flights by T-28 on 30 July 1970

Aircraft: T-28 510MH South Dakota School of Mines and Technology

Results reported by: John H. Hirsch

Temperature sensor: Weather Science, Inc. reverse flow thermistor

Aircraft Run	Tower Time	Aircraft Time	Tower IAS	Acft IAS	Tower Temp °C	Acft Temp °C	Tower Pres. mb	Acft Pres. mb	Acft Pres. Alt*
4	101140	101105	128	131	24.0	23.8	828.9	830.4	5189
6	102000	101910	128	132	24.7	24.0	828.8	830.4	5189
9	103143	103056	128	126	25.6	24.6	828.6	829.6	5210
11	104010	103937	129	129	25.7	25.2	828.6	828.4	5254

*Aircraft altimeter setting: 29.92 in Hg.

No measurement of static pressure defect.