REPORT NO. DOT- TSC- FAA- 71- 19

CLEAR AIR TURBULENCE RADIOMETRIC DETECTION PROGRAM

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JULY 1971
ANNUAL REPORT

Prepared for
U. S. DEPARTMENT OF TRANSPORTATION
FEDERAL AVIATION ADMINISTRATION
WASHINGTON, D. C. 20591

1. Report No. DOT-TSC-FAA-71-19	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle Clear Air Turbulence Radiometric Detection Program		5. Report Date JULY 1971
		6. Performing Organization Code TER
7. Author(s) George W. Wagner, G.G. Heroules, W.E. Brown		8. Performing Organization Report No.
9. Performing Organization Name and Address DOT/Transportation Systems Center 55 Broadway Cambridge, Mass. 02142		10. Work Unit No. FA-20
		11. Contract or Grant No.
12. Sponsoring Agency Name and Address U.S. Department of Transportation Federal Aviation Administration Washington, DC 20590		13. Type of Report and Period Covered Annual Report FY-71 July 1, 1970 - June 30, 1971
		14. Sponsoring Agency Code
15. Supplementary Notes		

16. Abstract

This report presents a review of accomplishments of the Clear Air Turbulence Detection Program. The objectives, instrumentation, supporting hardware and interfaces leading up to and including the test flights for the reporting period are given.

The ultimate goal of this program is the development of a remote method for detecting and thereby alerting high-altitude, high-speed aircraft in sufficient time to avoid the hazards associated with Clear Air Turbulence, CAT.

17. Key Words radiometer		18. Distribution Statement Unlimited	
19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages 47	22. Price

Form DOT F 1700.7 (8-69)

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SUMMARY

This report is intended to provide a review of the accomplishments of the Clear Air Turbulence Detection program for the period July 1, 1970 to June 30, 1971. It will discuss the objectives, instrumentation, supporting hardware and interfaces leading up to and including the test flights conducted in this reporting period.

The ultimate goal of this program is the development of a remote method for sensing and detecting and thereby alerting high-speed aircraft in sufficient time to avoid the hazards associated with Clear Air Turbulence (CAT). The long range objectives of the CAT program are:

1) Identification of meteorological parameters associated with this phenomenon,

2) Development of a passive measurement technique that is reliable,

3) Identification of aircraft characteristics associated with the phenomenon,

4) Formulation of turbulence design criteria for aircraft structures.

To achieve the long range objectives, four immediate goals for FY 1971 were first specified and are as follows:

1) Operational pre-flight test of a microwave radiometer to conditions of simulated flight,

2) Integration of the radiometer and recording instrumentation into a system for installation in an aircraft,

3) Perform a flight program to determine radiometer capabilities to detect clear air turbulence in predetermined turbulent areas,

4) Evaluate the data in terms of their usefulness for CAT detection.

The prototype of a dual-frequency radiometric sensor which would fill the objectives of the program had been developed and constructed at TSC for the passive detection and ranging of temperature anomalies associated with clear air turbulence.

During the development of the sensor a request and proposal for flight testing the capability of the sensor was submitted to NASA/FRC. A NASA/Flight Research Center agreement was reached with FRC to fly such an experiment on the B-57 aircraft with the provisions that the TSC package be a self-sufficient "plug-in" system maintained by TSC personnel. Furthermore, the system was also required to comply with the flight qualifications of FRC in terms of aircraft safety requirements. To assure compliance with their own flight specifications, NASA/FRC shipped a wing-tip external fuel tank for modification by TSC. FRC then added the stipulation that flight testing be concurrent with other test bed experiments on a non-interference basis.

To meet the flight program requirements, the dual-channel radiometric sensor was subjected to functional and electrical tests in-house, followed by environmental tests at a Government-approved test laboratory. There were no major catastrophic failures due to exposure to these flight simulation tests, and the radiometric sensor was considered operationally satisfactory for installation in the modified B-57 wing-tip tank. With the FRC approval of the B-57 type aircraft and final agreement for the location of the experiment on the aircraft, TSC was able to proceed with the flight hardware and flight-planning phase toward achieving the objectives previously set forth.

Accomplishments during the reporting period consisted of completion of the mechanical and electrical design of the total flight package, completion of working drawings and fabrication of the wing-tip pod modifications. The pod internal support structure and the pod radome, to accommodate the radiometer frequencies, were also designed and completed, as well as the design, fabrication, assembly, and test of the instrumentation package containing the radiometric sensor. Ancillary sensors, interconnecting cabling, a relay-function box for the remote tape-recording process, and a rail-type platform for easy and quick installation or removal of the complete self-contained package from the pod was also accomplished. Integration of the complete pod system package and functional electrical checks were accomplished at TSC in February 1971. The flight system and its supporting ground test equipment were then shipped to NASA/FRC, California.

Flight operations were set up at NASA/FRC on February 16, 1971. FRC completed installation of the cockpit control switch and wiring to the aircraft wing tip and mated the pod flight system to the wing tip. Final pre-flight checks on the aircraft indicated the CAT system was operating satisfactorily and ready for flight.

A total of six flights were accomplished during the period of May 24 to June 2, 1971. The flight plans consisted of shakedown, calibration, and CAT search flights. The last three flights yielded four-and-a-half hours of recorded tape data; however, the pilot reported that no clear air turbulence was encountered.

It is planned to continue the flight program in FY 1972 with FAA support. NASA/FRC will continue the flight support on a concurrent or individual flight basis as future FRC schedules permit. Significant data, test results, and reports will be subsequently made available to NASA.

TECHNICAL DISCUSSION

The ever-increasing operational altitudes and speeds of advanced aircraft prompted earlier studies and measurements of the atmospheric environment by various other agencies. Those programs were conducted specifically to define better high-altitude clear air turbulence in order to improve "structural design" criteria. It was at a later date that attention was directed to the need for a reliable airborne method to detect remotely clear air turbulence (CAT) for the purpose of aircraft avoidance maneuvers or minimizing the effects of severe hazards known to be associated with this CAT meteorological phenomenon.

As a result of intensive in-house efforts, a prototype of a dual-channel radiometric sensor was developed and constructed at TSC for the passive detection and ranging of temperature anomalies associated with clear air turbulence.

MILLIMETER RADIOMETRIC SENSOR

The 60 GHz radiometer is a versatile dual-channel sensor system for performing accurate radiometric measurements at a wavelength of 5mm. The unit is designed for aircraft installation. Its principal use is the detection of atmospheric temperature anomalies along the horizontal flight path forward of an aircraft at flight altitudes in the range from 30,000 to 60,000 feet. The radiometer is a complete sensor system consisting of two radiometric receivers packaged integral with one common lens-corrected horn antenna. Each radiometric receiver is fed from a common orthogonal-mode transducer located at the antenna output. Atmospheric temperature signals are simultaneously processed by the two receiver channels which operate at nominal frequencies of 52 and 58 GHz. The receivers are separately tunable over $\pm$1GHz about their nominal operating frequencies.

The radiometric modes of operation are modified absolute-temperature modes. The modification introduced in the absolute modes provides for adjustment of either or both radiometer output signals to a reference level corresponding to the ambient temperature at the aircraft flight altitudes.

The technique for absolute-temperature measurement at microwave frequencies takes advantage of the inherent ability of a radiometer to provide a precise measurement of noise temperature differences. A known source of noise power is required only for laboratory calibration of the instrument. The significant features of the technique are (a) all rf input circuit components may be operated at ambient temperature, (b) the introduction of a switch at the signal input port of the radiometer to provide a radiometer zero, and (c) the injection of a noise source in the signal path to provide absolute calibration of the radiometer zero.

Figure 1 presents a general idea of CAT measurement technique. Physically, the radiometric sensor is designed for aircraft wing-pod mounting but not limited to this location.

Dimensionally, the radiometer is 16.75 inches square on the front face and 13 inches deep. It weighs 65 pounds.

Flight qualification of the radiometer was conducted at the Acton Test Laboratory, Acton, Massachusetts. The simulated environmental flight test was performed in accordance with specifications compiled by TSC for a "non-destructive, one available" test and to meet the requirements of NASA/FRC Specification No. 21-2, flight assurance testing (environmental).

Exposure to simulated flight consisted of:

1. Temperature-altitude test (operational): 65,000 feet and -54°C.

2. Shock test (operational): 5g peak amplitude for 3-6 mil-sec.

3. Vibration test (operational): vertical axis, 5-500 cps, 4.0 minutes; thrust axis, 5-500 cps., 4.0 minutes, 2g's 0-to-peak; lateral axis, 5-500 cps, 4.0 minutes, 2g's 0-to-peak.

Results of simulation test: A transistor and potentiometer in the klystron power supply failed during initial chamber pump-down. After replacement of the electronic component, the tests were rerun and completed satisfactorily.

FLIGHT PROGRAM

With the availability of the dual-frequency radiometric sensor at TSC, the next and most important step was to investigate the capability of the sensor to detect clear air turbulence. To accomplish this task, a series of flight tests were planned at altitudes of 30,000 to 60,000 feet. The technical effort leading up to the Flight Test milestone included the following accomplishments:

1. Definition and approval of a test bed aircraft,

2. Instrumentation system package design and assembly,

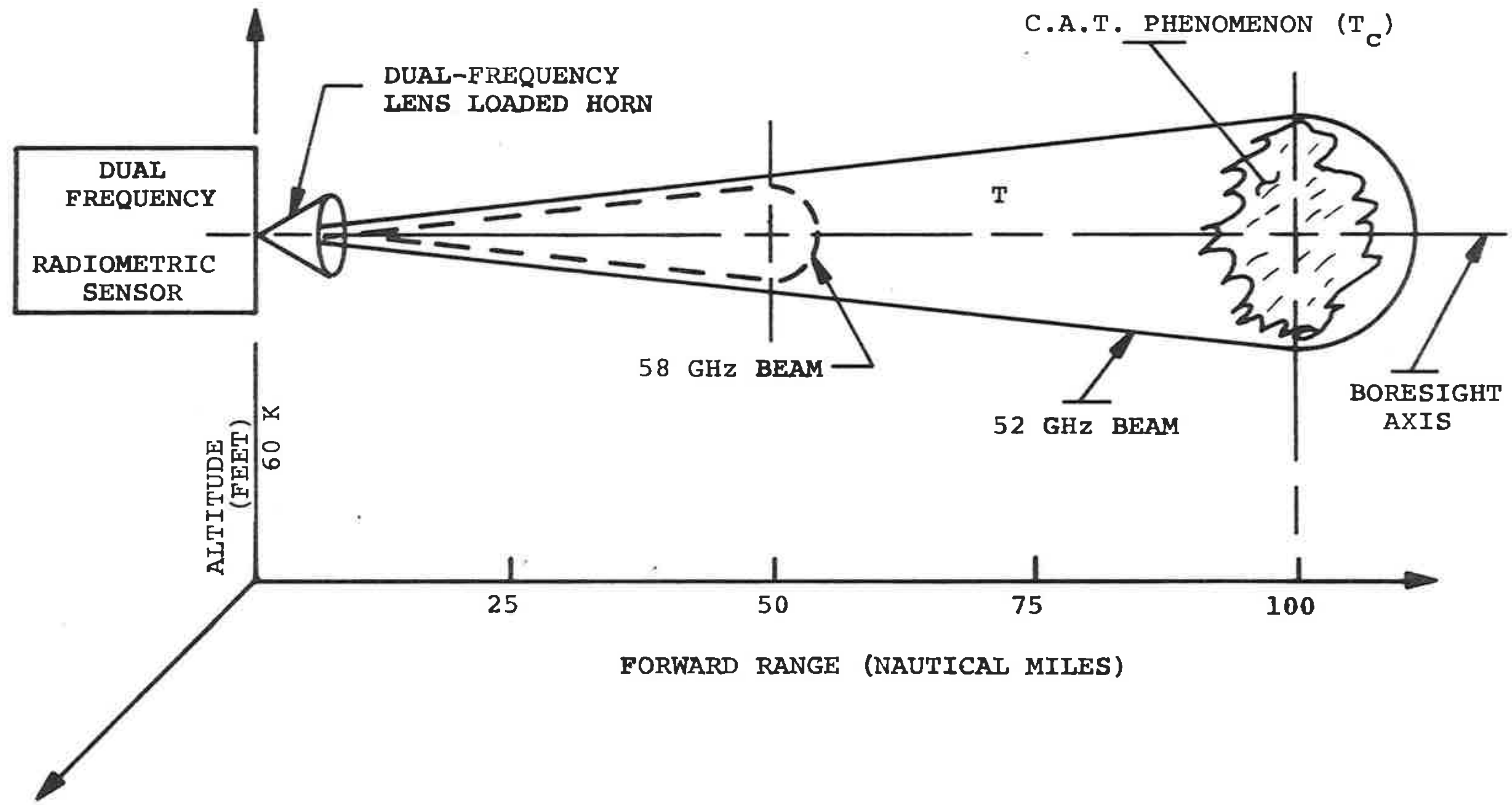


Figure 1. Meterological Phenomenon as Sensed by dual frequency Radiometer

3. Wing-tip pod acquisition and modification,

4. Flight system integration,

5. Pre-flight ground test equipment design and assembly,

6. Aircraft interfacing procedure,

7. Aircraft wiring and control switch installation,

8. "Operating Instructions" compilation,

9. Data analysis equipment and reduction.

The flight hardware configuration was dependent on the type of aircraft to be used as a test bed and the location of the experiment on that aircraft. Various high-altitude aircraft were investigated, and the voluminous data were boiled down to the earliest available suitable aircraft for initial flight test. The aircraft is a twin engine jet B-57 Canberra located at and operated by NASA/FRC, Edwards AFB, California. It is capable of reaching 50,000 feet altitude and can accommodate installation of the experiments in the nose section, bomb bay, wing bays, and wing tip. Use of this aircraft for the CAT program was approved by NASA/FRC with the stipulation that the TSC experiment locate in a wing-tip pod as an independent self-operational flight package with minimum modification to the aircraft.

FLIGHT OPERATIONS

TSC flight operations at NASA/FRC were coordinated with FRC and conducted in accordance with the requirements previously specified, that is, on a non-interference basis concurrent with other experiments. TSC personnel handled all the CAT equipment operations and test aspects of the program. However, FRC provided invaluable assistance and cooperation with aircraft interface and flight planning.

A breakdown of the initial flight operation is listed below for the period February through June 1971. The events may reflect unusual delays, but these should not be construed as unreasonable since occurring problems and priority work could not be predicted or controlled.

SIGNIFICANT EVENTS

February 12, 1971	TSC flight package arrived at NASA/FRC.
February 16, 1971	Final assembly started.
February 19, 1971	Pre-flight electrical work completed.
February 22, 1971	Positioned pod to wing tip without latching bolts to check alignment.
February 23, 1971	Program review meeting with FRC operation and engineering personnel.
February 24, 1971	FRC equipment inspection and discrepancies-corrections completed.
February 25, 1971	B-57 departed for Langley RC to trouble-shoot Langley experiment. TSC personnel returned to Cambridge, MA.
April 19, 1971	B-57 returned to NASA/FRC. TSC personnel resumed flight operations.
April 22, 1971	Aircraft flight test for Viking project.
April 23, 1971	CAT experiment electrical recheck completed.
April 26, 1971	FRC started installation of control switches in cockpit for CAT project.
April 29, 1971	CAT pod mated and bolted to the wing tip for the first time.
April 30, 1971	Completed electrical interface and CAT control switch installation in the aircraft.
May 5, 1971	Final pre-flight electrical and mechanical checks completed on CAT system. Ready for flight.

May 7, 1971	<u>Flight #1</u> - First shakedown flight. Failure to record any data on tape was attributed to the recorder going into the rewind mode just prior to take-off. Post-flight checks showed that as a result of recycling the recorder run switch in the cockpit, the recorder could go to any mode. The problem was resolved when Genisco Co. advised that an electronic component was left out of the control circuit during manufacture. Failure of the CAT radiometer to function was traced to low voltage (22 VDC) at the wing tip. A nominal voltage of 26.5 is required for the sensor to operate.
May 10, 1971	<u>Flight #2</u> - This was a flight concurrent with the Viking project. The aircraft was ferried to El Centro, California for a Viking installation. While preparing the equipment for a second CAT shakedown flight the recorder tape jammed and could not be corrected before departure. The CAT system was placed on the off mode for this flight.
May 11, 1971	At El Centro, TSC personnel replaced the jammed tape and prepared the CAT experiment for Flight #3.
May 12, 1971	<u>Flight #3</u> - This was a flight concurrent with the Viking project to Nasa Langley Research Center (LeRC), Virginia. As a temporary fix, the CAT recorder was placed in the record mode at pre-flight and left in the run position until the first refueling stop, at which time the experiment was shut down for the remainder of the flight.
May 19, 1971	Aircraft back at NASA/FRC. A review of the two hours of tape recorded during flight #3 revealed the CAT detector was inoperative due to low voltage at the wing tip. The altitude transducer was also found inoperative and the velocity probe damaged. Data were considered insufficient and inaccurate for analysis.

May 21, 1971	Corrective actions completed. The Genisco Company corrected the tape recorder malfunction by installing the missing capacitor. FRC increased the electrical wiring capacity in the aircraft wing and this increased the voltage to a marginal 25.5 volts. The altimeter was returned to the Edcliff Company for correction, and the unit was replaced by a transducer on loan from FRC. The damaged velocity probe was replaced.
May 24, 1971	Flight #4 - Individual shakedown and CAT search flight. This flight was aborted after one hour due to aircraft problems. Although no CAT search was attempted or encountered, the one hour of recorded data did provide some useful information for refining the calibration and operations of the various sensor functions.
June 1, 1971	Flight #5 - An individual CAT search flight of a two-hour duration. Two hours of recorded data were obtained over the Mt. Whitney area of the Sierra Nevada mountain range. The pilot reported light turbulence encountered at 35,000 and 25,000 feet, respectively, and the preplanned flight pattern was exercised.
June 2, 1971	Flight #6 - An individual CAT search flight of 1.5 hours duration. No turbulence was encountered while operating over the Mt. Whitney area.

Flight planning was prepared the day before flight and was based upon the CAT forecast from the most recent weather observations. The pilot was briefed on the forecast conditions and on the procedure to follow in the event of a CAT encounter, or he was told to perform special flight test maneuvers. A sample flight plan is shown in Appendices A and B.

DATA REVIEW AND ANALYSIS

ACQUISITION AND PROCESSING

The present flight system package is designed to collect data to determine the feasibility of the experimental radiometer to detect clear air turbulence. The data are used to calculate range measurements and false alarm rates.

Flight data are obtained by converting the meteorological parameters into voltages and recording these voltage signals on an airborne 14 channel magnetic tape recorder. The flight parameters collected include the two localized temperatures associated with CAT using the radiometric sensor and supplemental data such as ambient temperature, air velocity, aircraft pitch and roll attitude, pressure altitude, accelerations, and real time. To process the data, the airborne tape-recorded data are converted back to actual flight parameter values through a playback recorder and read directly onto display meters, or as oscillographs, or through a computer as printout data. The ground support equipment for processing the data tape is located only at DOT/TSC Cambridge, Massachusetts; therefore, an analysis is not accomplished in the field. At the location of flight operations, the procedure is to review any recorded tape after each flight. The information thus obtained is used mainly for future flight planning and recalibration of the sensor signals when the data indicates the need exists. Post-flight data in the field are usually tabulated in voltage form or as oscillographs for the cursory review. (Tables 1 and 2)

DATA ANALYSIS

The data reviewed in this report were obtained from B-57 flights out of NASA/FRC, California. The following flights were performed.

Flight #1-----May 7, 1971-----Shakedown-----No data

Flight #2-----May 10, 1971-----Shakedown-----No data

Flight #3-----May 12, 1971-----Shakedown-----2-hour tape

Flight #4-----May 26, 1971-----Shakedown & CAT Search-----
1-hour tape

Flight #5-----June 1, 1971-----Calibration & CAT Search-----
2-hour tape

Flight #6-----June 2, 1971-----Calibration & CAT Search-----
1.5-hour tape

Flight #3 Tape Review

This was a ride-along flight with the Viking project to Langley Research Center. The two-hour tape was obtained on the first leg of the flight (from El Centro, California to Denver, Colorado) at altitudes of 37,000 and 41,000 feet.

The data tabulated in voltage form indicated that the radiometer, velocity, and pressure altitude sensors were inoperative for reasons previously stated. The data on this tape were considered insufficient and inaccurate for further analysis but were useful in identifying the deficiencies of the sensor and aircraft equipment.

Flight #4 Tape Review

Flight #4 was an individual CAT flight over the Mt. Whitney area of the Sierra Nevada Mountain Range (within 150 miles of NASA/FRC) at an altitude of 30,000 feet. The pilot aborted the flight after one hour. Consequently, only the special maneuvers part of the flight plan was recorded.

Flight plan 4 is shown in Appendix A. The raw data in voltage form are shown in Table 1 for significant points in flight. Table 2 provides the data conversion of voltage signal to flight parameter real values.

In addition, oscillographs of the radiometric sensor channels A and B, altitude and outside temperature for two active parts of this flight are shown in Figures 2 and 3.

Although no turbulence was predicted or encountered, the data indicate that radiometric measurements of lapse rate were recorded during ascent, descent, and special maneuvers of this calibration flight.

TABLE I. FLIGHT TEST DATA - RECORDED SENSOR VOLTAGES.

CHANNEL NO.		WING	TIP		3	11	1	13	2	6	4	10	14	5	9	7	8	12	
TAPE FOOTAGE	CLOCK TIME A C	MASTER PANEL VOLTS	VOM METER VOLTS	P/C GEN.	ACCEL. #1 THRUST	ACCEL. #2 LAT.	ACCEL. #3 VERT.	GYRO. #1 PITCH	GYRO #2 ROLL	TEMP. #1 IN	TEMP. #2 OUT	INCLIN. #1 PITCH	INCLIN. #2 ROLL	ALT	RAD CH. "A" 52GHz	RAD CH. "B" 58GHz	VEL	TIME CODE GEN.	REMARKS
28	EQUIPMENT POWER "ON"																		
29	10:50	26.0	27.0		-1.85	-2.24	-2.15	+3.07	+2.2	-2.23	-0.93	-2.14	-2.2	-4.47	+2.36	+2.55	-1.0		Before taxi
100					-1.89	-2.3	-2.14	+2.90	+2.29	-2.28	-0.99	-2.10	-2.33	-4.45	+2.29	+2.55	-2.2		Taxi out
151	START OF TAKE OFF ROLL													-4.46			-1.0		
153					-1.85	-2.24								-4.46			-4.2 -3.2		velocity signal saturates
160					-1.85	-2.24	-2.2	-0.77	+2.34	-2.33	-1.03	-3.34	-2.37	-4.39	+2.32	+2.48	-3.2		
176	PILOT REPORTS: 5,000 feet @ 295 knots, heading 240°, temp 24°C, rate of climb 2000'/min																		
176					-1.97	-2.24	-2.17	-0.25	+3.70	-2.23	-0.91	-2.75	-2.40	-3.8	+2.34	+2.13			
194	PILOT REPORTS: 10,000 feet @ 305 knots, Rt. turn, temp 15°C, rate of climb 0																		
194					-1.93 -1.76	-2.24	-2.16	-1.4	+3.98	-2.32	-0.56	-2.60	-2.28	-3.02	+2.35	+2.22			
238	11:14	PILOT REPORTS: Run #1 (Flt. Plan) 10,000 feet, heading 010°, level, weather clear																	
238					-1.84	-2.24	-2.13	+3.09	+2.67	-2.40	-0.57	-2.13	-2.27	-3.07	+2.35	+2.20			
288					-1.83	-2.24	-2.14	+1.96	+6.0			-2.3	-2.3		+2.35	+2.20			
295	PILOT REPORTS: heading 340° @ 240 knots, temp 10°C																		
325					-1.84	-2.23	-2.14	+2.20	+2.80	-2.3	-0.50	-2.3	-2.3	-3.13	+2.6	+3.0			
335	PILOT REPORTS: climbing to 30,000 feet																		
335					-1.85	-2.23	-2.14	-0.22 +0.10	-2.37	-2.30	-0.52	-2.8	-2.25	-3.0	+2.43	+2.23			
385					-1.85	-2.23	-2.14	+0.4	-2.5	-2.2	-0.61	-2.70	-2.23	-1.8	+2.6	+2.4			Estimate 20,000 ft.

DOT-TSC-CAT FLIGHT DATA

DATA CLASS: VOLTAGES (TAPE)		TSC-FLT #4	FRC-FLT #35
FLT. PLAN: SHAKEDOWN	TABLE #1	PG.#1	FLIGHT DATE: 5/26/71

TABLE I. FLIGHT TEST DATA - RECORDED SENSOR VOLTAGES (Continued).

CHANNEL NO.		WING TIP			3	11	1	13	2	6	4	10	14	5	9	7	8	7 - 9
TAPE FOOT-AGE	CLOCK TIME A/C	MASTER PANEL VOLTS	VOM METER VOLTS	P/C GEN.	ACCEL. #1 THRUST g's	ACCEL. #2 LAT. g's	ACCEL. #3 VERT. g's	GYRO. #1 PITCH ± DEG	GYRO. #2 ROLL ± DEG	TEMP. #1 IN °F	TEMP. #2 OUT °F	INCLIN. #1 PITCH DEG	INCLIN. #2 ROLL DEG	ALT. K Feet	RAD CH. "A" 52GHz	RAD CH. "B" 58GHz	VEL MPH	RADIOM $T_B - T_A$
447	PILOT REPORTS: Run #3, stabilize @ 30,000 feet, @ 275 knots, level																	
447					−.05	−.05	+.05	+.75	+.87	+60	+5	+.75	+1.5	32.1	83.85	95.46		11.61
482	PILOT REPORTS: Run #4 maneuvers																	
483	+5° climb				+.15	+.15	−.1	+1.5	−.3	+61.8	+5	+.6	+1.35	31.7	83.52	94.35		10.83
484.5	+10° climb				+.15	+.15	−.1	+5	+.51	+61.3	+1	+.6	+1.0	31.9	85.83	93.61		7.78
485.7	+15° climb				+.05	+.1	−.15	+10	+.29	+61	+6.5	+1.5	+3	32.3	78.01	93.98	SATURATED	15.97
487	-5° nose down				+.2	+.1	0	SAT.	+.54	+60	+5.5	+2.5	+1.2	32.5	79.67	94.72		15.05
489	-10° nose down				+.25	+.1	0	−5°	+.6	+60.5	+11	+4.5	0	35.3	79.01	96.57		17.56
490.2	-15° nose down				+.15	+.05	0	−10	+.54	+60	+5.5	+4.4	+.3	32.0	86.49	96.94		10.45
491.5	Back to level				+.2	+.05	0	−14	+.43	+60.5	+4	+3.2	0	32.0	82.53	96.57		14.0
494	Rt side slip				+.1	+.05	+.05	0	+.93	+60	+4	+1.5	0	32.0	82.53	96.57		14.0
496	Left side slip				+.2	+.05	+.05	+2	−.49	+60	+4	+1.0	−.6	33.6	85.17	95.46		10.29
497.2	Back to level				+.1	+.1	0	+2.4	+1.34	+60	+3	+1.4	+2.8	34.0	86.16	95.83		9.67
499					+.2	+.05	0	+1.2	+1.14	+59	+5	+1.5	+.75	32.0	85.83	96.2		10.37
500 - 537	Descending & level off at 20,000 feet, per run #9, airspeed 288 knots - T = -5°C																	
552					+.2	+.05	0	+.1	+.25	+59	−18	+3	+1.2	23.0	80.0	88.06		8.06
574	11:51	Leaving 20,000 feet, descending to 10K feet @ 6° nose down angle																
598					+.05	+.05	−.15	+1.5	+.44	+60	+16	−3	0	12.85	75.7	80.06		4.36

DOT-TSC-CAT FLIGHT DATA	DATA CLASS: ACTUAL REAL VALUES	TSC-FLT #4 FRC-FLT #35
	FLT. PLAN: SHAKEDOWN TABLE #1	PG.#2 FLIGHT DATE: 5/26/71

TABLE I. FLIGHT TEST DATA - RECORDED SENSOR VOLTAGES (Continued).

CHANNEL NO.		WING TIP			3	11	1	13	2	6	4	10	14	5	9	7	8	12	
TAPE FOOT AGE	CLOCK TIME A C	MASTER PANEL VOLTS	VOM METER VOLTS	P C GEN	ACCEL #1 THRUST	ACCEL #2 LAT	ACCEL #3 VERT	GYRO #1 PITCH	GYRO #2 ROLL	TEMP #1 IN	TEMP #2 OUT	INCLIN #1 PITCH	INCLIN #2 ROLL	ALT	RAD CH "A" 52GHz	RAD CH "B" 58GHz	VEL	TIME CODE GEN	REMARKS
602 -to- 610							-2.12 -1.77 +6.4 -2.13	VOLTAGE GOES THRU 0 @ THE 2G PULL OUT POINT											
620					-1.88	-2.26	-2.15	+3.69	+3.05	-2.07	-1.02	-2.27	-2.26	-4.4	+2.27	+2.0	-3.2		
630					-1.88	-2.24	-2.15	+2.9	+3.22	-2.07	-1.0	-2.05	-2.16	-4.44	+2.24	+1.94	-3.0		
645					-1.88	-2.24	-2.15	+3.64	+2.5	-2.10	-0.92	-2.04	-2.2	-4.44	+2.63	+2.8	-1.8		
690					-1.88	-2.24	-2.15	+3.45	+2.29	-2.18	-0.85	-2.07	-2.18	-4.44	+2.3	+1.97	-1.0		
696	EQUIPMENT POWER OFF																		
	12:06	24.5																	

DOT-TSC-CAT FLIGHT DATA

DATA CLASS: VOLTAGES (TAPE) TSC-FLT #4 FRC-FLT #35

FLT. PLAN: SHAKEDOWN TABLE #1 PG.#3 FLIGHT DATE: 5/26/71

TABLE II. CONVERSION OF TABLE I VOLTAGES TO FLIGHT PARAMETERS.

CHANNEL NO.		WING	TIP		3	11	1	13	2	6	4	10	14	5	9	7	8	7 – 9	
TAPE FOOTAGE	CLOCK TIME A C	MASTER PANEL VOLTS	VOM METER VOLTS	P C GEN	ACCEL. #1 THRUST g's	ACCEL. #2 LAT. g's	ACCEL. #3 VERT. g's	GYRO. #1 PITCH ± DEG	GYRO. #2 ROLL ± DEG	TEMP. #1 IN °F	TEMP. #2 OUT °F	INCLIN. #1 PITCH DEG	INCLIN. #2 ROLL DEG	ALT. K feet	RAD CH -A- 52GHz DEG	RAD CH -B- 58GHz DEG	VEL MPH	RADIOM T_B T_A	REMARKS
28	POWER	"ON"																	
29	10:50	26.0	27.0		0	0	0	-	0	+71	+12	-.15	0	0	77.68	94.35	0	16.67	
100					+.2	+.3	+.05	-.2	0	+73	+15	-1.5	+2	0	75.37	94.35	?	18.98	
151	START "TAKE OFF"													0			0		
153					0	0	-	+8						0					
160					0	0	-.25	+8	+.06	+75	+16	+17.0	+2.5	.2	76.36	91.76	? 268	15.4	VOLTAGE SIGNAL SATURATE
176	PILOT REPORTS: 5,000 feet @ 295 knots, temp 24°C, climbing																		
176					+.6	0	-.1	+7.5	+1.75	+71	+11	+8.2	+3	4.7	77.02	78.81		1.79	
194	PILOT REPORTS: 10,000 feet @ 305 knots, rt. turn, temp 15°C																		
194					+.4	0	-.05	+10	+2.0	+73	-5	+6.0	+1.2	10.25	77.35	82.14	SATURATED	4.79	
238	11:14 PILOT REPORTS: 10,000 feet, run #1, stabilize at this alt.																		
238					-.05	0	+.1	0	+.48	+78	-4	-1.0	+1	10.1	77.35	81.4		4.05	
288					-.1	0	+.05	+2.5	SAT	-	-	+1.5	+1.5	-	77.35	81.4		4.05	
295	PILOT REPORTS: 240 knots, temp 10°C																		
325					-.05	-.05	+.05	+2	+.64	+73.5	-7.5	+1.5	+1.5	9.75	85.5	111.0		25.5	
335	PILOT REPORTS: climbing to 30,000 feet																		
335					0	-.05	+.05	+7.5	+.10	+73.5	-7	+9.0	+.75	10.45	80.0	82.51		2.51	
385					0	-.05	+.05	+6	+.26	+69	-2.5	+7.5	+.45	23.15	85.5	88.8		3.3	

DOT-TSC-CAT FLIGHT DATA

DATA CLASS: ACTUAL REAL VALUES   TSC-FLT #4   FRC-FLT #35

FLT. PLAN: SHAKEDOWN   TABLE #2   PG#1   FLIGHT DATE: 5/26/71

TABLE II. CONVERSION OF TABLE I VOLTAGES TO FLIGHT PARAMETERS (Continued).

CHANNEL NO.		WING TIP			3	11	1	13	2	6	4	10	14	5	9	7	8	7 − 9
TAPE FOOTAGE	CLOCK TIME A/C	MASTER PANEL VOLTS	VOM METER VOLTS	P/C GEN.	ACCEL. #1 THRUST	ACCEL. #2 LAT.	ACCEL. #3 VERT.	GYRO. #1 PITCH	GYRO. #2 ROLL	TEMP. #1 IN	TEMP. #2 OUT	INCLIN. #1 PITCH	INCLIN. #2 ROLL	ALT. K	RAD CH "A" 52GHz	RAD CH "B" 58GHz	VEL.	RADIOM $T_B - T_A$
602 to 610							+1.5 +1.9 SAT +.1											
620					+.15	+.1	0	-1.4	+.93	+33	+16	+1.0	+.9	1.5	74.71	74.0	268	-.71
630					+.15	0	0	-.2	+1.17	+33	+16	-2.3	-.6	0	73.72	71.78	240	-1.94
645					+.15	0	0	-1.3	+.25	+34.5	+11	-2.4	0	0	86.49	103.6	112	+17.11
690					+.15	0	0	-0.8	0	+38	+8	-1.8	-.3	0	75.7	72.89	0	-2.81
696	POWER	"OFF"																
	12:06	24.5																

DOT-TSC-CAT FLIGHT DATA

DATA CLASS: ACTUAL VALUES TSC-FLT #4 FRC-FLT #35

FLT. PLAN: SHAKEDOWN TABLE #2 PG.#3 FLIGHT DATE: 5/26/71

TABLE II. CONVERSION OF TABLE I VOLTAGES TO FLIGHT PARAMETERS (Continued).

CHANNEL NO. TAPE FOOTAGE	CLOCK TIME A.C.	WING MASTER PANEL VOLTS	TIP VOM METER VOLTS	P/C GEN.	3 ACCEL. #1 THRUST	11 ACCEL. #2 LAT.	1 ACCEL. #3 VERT.	13 GYRO. #1 PITCH	2 GYRO. #2 ROLL	6 TEMP. #1 IN	4 TEMP. #2 OUT	10 INCLIN. #1 PITCH	14 INCLIN. #2 ROLL	5 ALT.	9 RAD CH "A" 52GHz	7 RAD CH "B" 58GHz	8 VEL	7 – 9 TIME CODE GEN	REMARKS
447	PILOT REPORTS: 30,000 feet over Mt. Whitney, heading 145° @ 275 knots, level																		Run #3
447					-1.84	-2.23	-2.14	+2.7	+3.0	-2.0	+0.78	-2.25	-2.3	-0.9	+2.55	+2.58			
482	PILOT STARTS AIRCRAFT MANEUVERS PER RUN #4 OF FLT PLAN.																		
483					-1.88	-2.27	-2.17	+2.47	+2.05	-2.04	+0.78	-2.24	-2.29	-0.92	+2.54	+2.55			
484.5	+5° climb				-1.88	-2.27	-2.17	+0.69	+2.70	-2.03	+0.69	-2.24	-2.27	-0.91	+2.61	+2.53	SATURATED		
485.7	+10° climb				-1.86	-2.26	-2.18	-1.30	+2.44	-2.02	+0.81	+2.3	-2.4	-0.89	+2.37	+2.54			
487.0	+15° climb				-1.89	-2.26	-2.15	-5.14	+2.72	-2.0	+0.79	-2.37	-2.28	-0.85	+2.42	+2.56			
489	-5° nose down				-1.90	-2.26	-2.15	+0.51	+2.77	-2.01	+0.91	-2.5	-2.2	-0.77	+2.4	+2.61			
490.2	-10° nose down				-1.88	-2.25	-2.15	+1.21	+2.72	-2.0	+0.87	-2.49	-2.22	-0.79	+2.63	+2.62			
491.5	-15° nose down				-1.89	-2.25	-2.15	+2.72	+2.63	-2.01	+0.79	-2.41	-2.2	-0.79	+2.51	+2.61			
494	BACK TO LEVEL				-1.87	-2.25	-2.14	+3.08	+3.05	-2.0	+0.75	-2.3	-2.2	-0.79	+2.51	+2.61			
496	RT. SIDE SLIP				-1.89	-2.25	-2.14	+2.19	+1.9	-1.99	+0.75	-2.27	-2.16	-0.87	+2.59	+2.58			
497.2	LEFT SIDE SLIP				-1.87	-2.26	-2.15	+2.06	+3.36	-1.99	+0.73	-2.29	-2.39	-0.86	+2.62	+2.59			
499	BACK TO LEVEL				-1.89	-2.25	-2.15	+2.54	+3.2	-1.98	+0.78	-2.3	-2.25	-0.85	+2.61	+2.6			
500 – 537	DESCENDING & LEVEL OFF AT 20,000 feet per Run #9, airspeed 280 knots, temp -5°C																		
552					-1.89	-2.25	-2.15	+3.03	+2.5	-1.98	+0.26	-2.4	-2.28	-1.82	+2.43	+2.38	-3.2		
574	11:51 PILOT REPORTS: leaving 20,000 feet and descending to 10,000 feet @ a 6° nose down angle																		
598	PILOT STARTING 2G PULL OUT 11,000 FEET.				-1.86	-2.25	-2.12	+2.42	+2.64	-2.0	+0.8	-1.8	-2.2	-2.75	+2.3	+2.18	-3.2		

DOT-TSC-CAT FLIGHT DATA

DATA CLASS: VOLTAGES (TAPE) | TSC-FLT #4 | FRC-Flt #35

FLT. PLAN: SHAKEDOWN | TABLE #2 | PG.#2 | FLIGHT DATE: 5/26/71

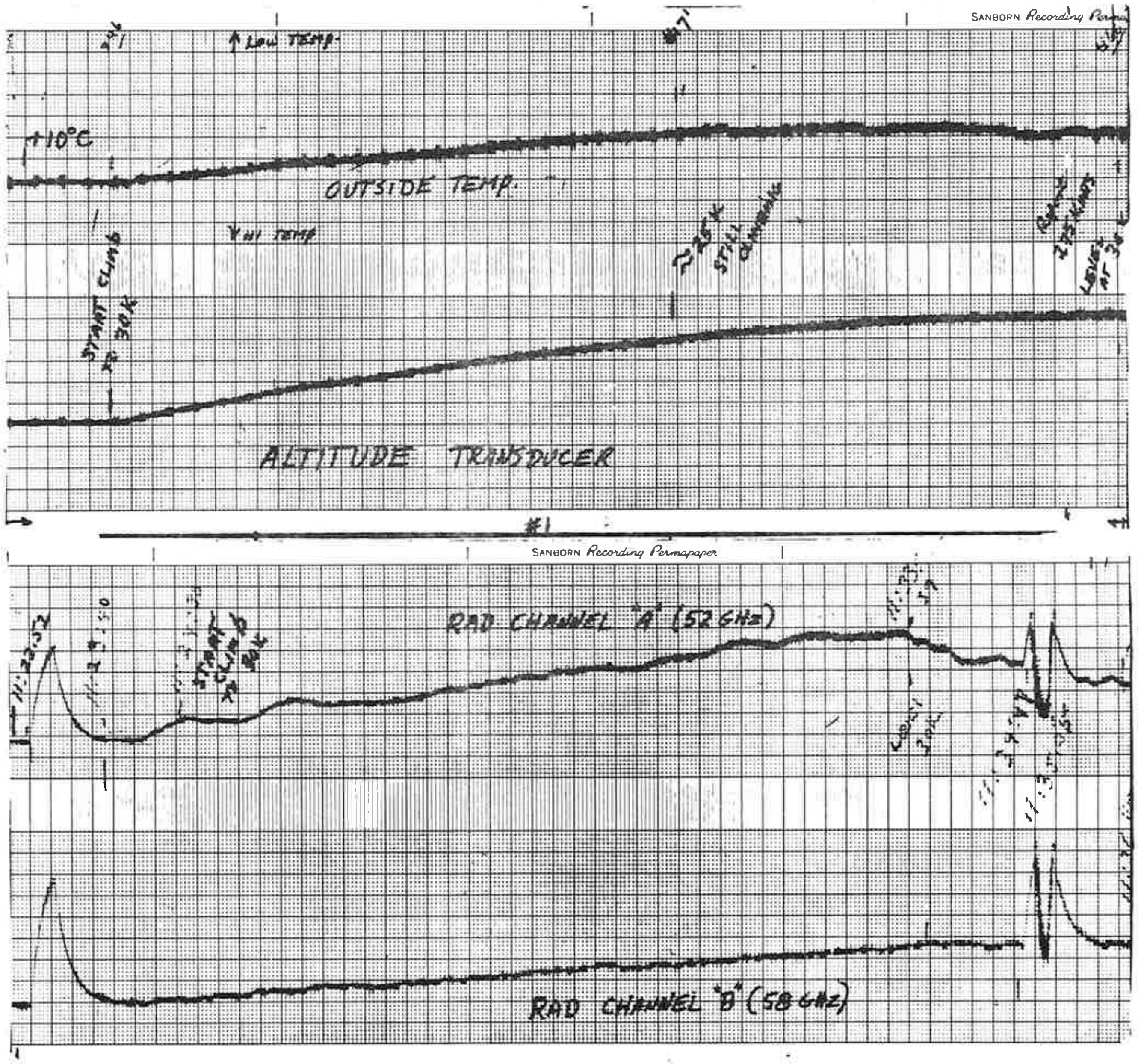


Figure 2. Data Chart Recordings (Flight 4).

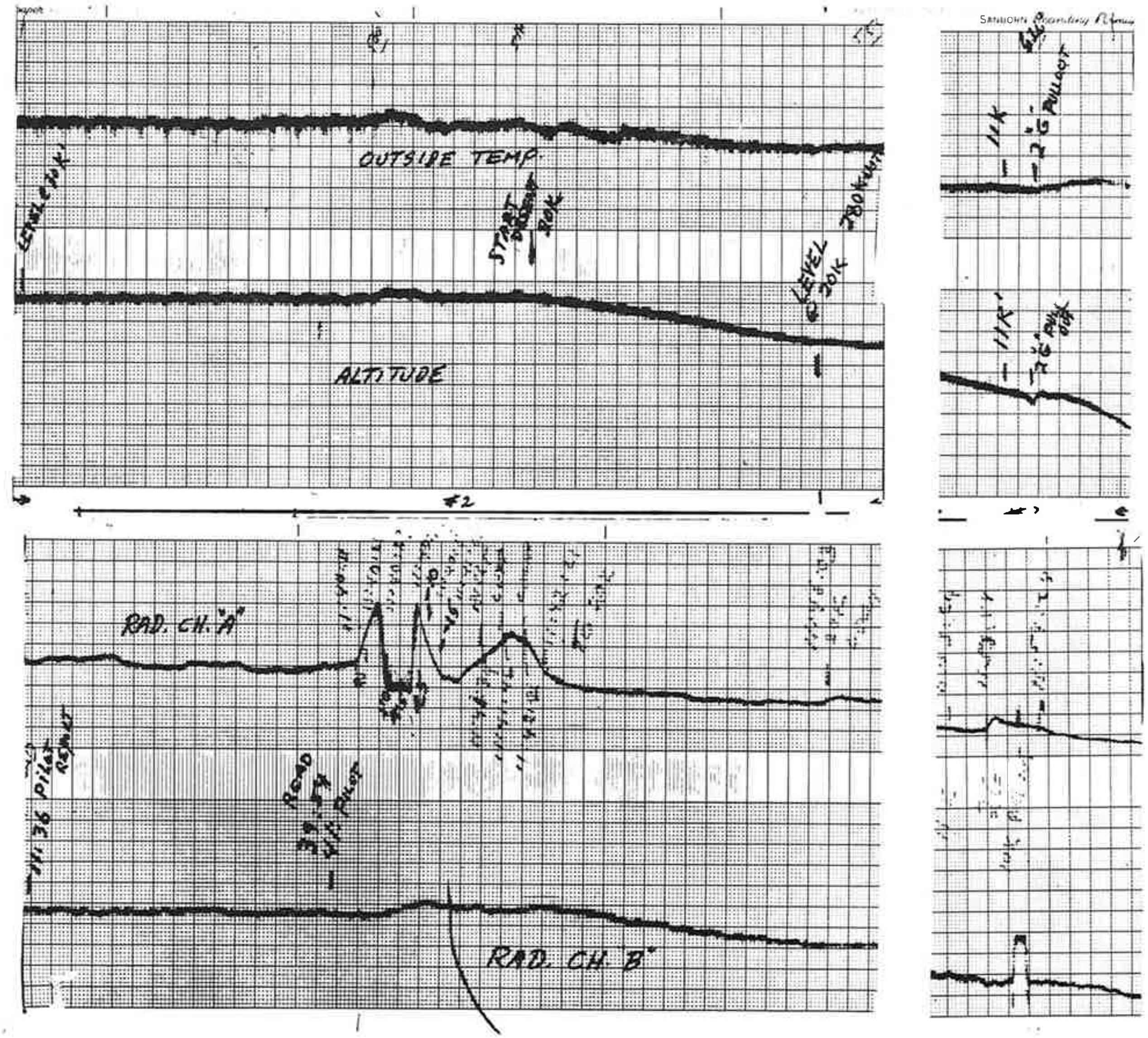


Figure 3. Data Chart Recordings (Flight 4).

Flight #5 Tape Review

This was an individual DOT flight for the purpose of a search for CAT at 30,000 feet. Weather stations had no reports of turbulence within range of the aircraft. Therefore, the flight planning consisted of a pilot search over the Mt. Whitney area. Two hours of data were recorded and processed in the same manner as for Flight #4. The tabulated data were not included in this report since the flight plan and the overflight search area were similar to Flight #4. As a result, the data values for the various flight conditions were close enough to deduct the same evaluation. The oscillograph in Figure 4 indicates the same radiometric measurements of lapse rate.

The difference in this flight is that the pilot did encounter what he reported as light turbulence over the mountain range at both 35,000 and 25,000 feet and, as a result, proceeded with the preplanned flight pattern, as shown with the attached plan No. 4 (Appendix A). Recorded data during these periods of flight showed no appreciable changes to indicate turbulence, nor did the ancillary sensors on board correlate with the pilot's report of turbulence.

Flight #6 Tape Review

This individual DOT flight was a repeat of Flight #5. Meteorological conditions were less active and the flight uneventful. It provided no additional useful information and, therefore, will not be discussed further.

Conclusions

The following conclusions are based upon a review analysis of the data obtained during 4.5 hours of the initial calibration flights of the DOT/CAT detection flight system experiment. These flights were planned and conducted out of NASA/FRC, Edwards, California at altitudes of 20,000 to 40,000 feet above the Sierra Nevada mountain range.

1) The area of investigation was too limiting (within 200 miles of Edwards AFB) for CAT search flights, but adequate for calibration flights.

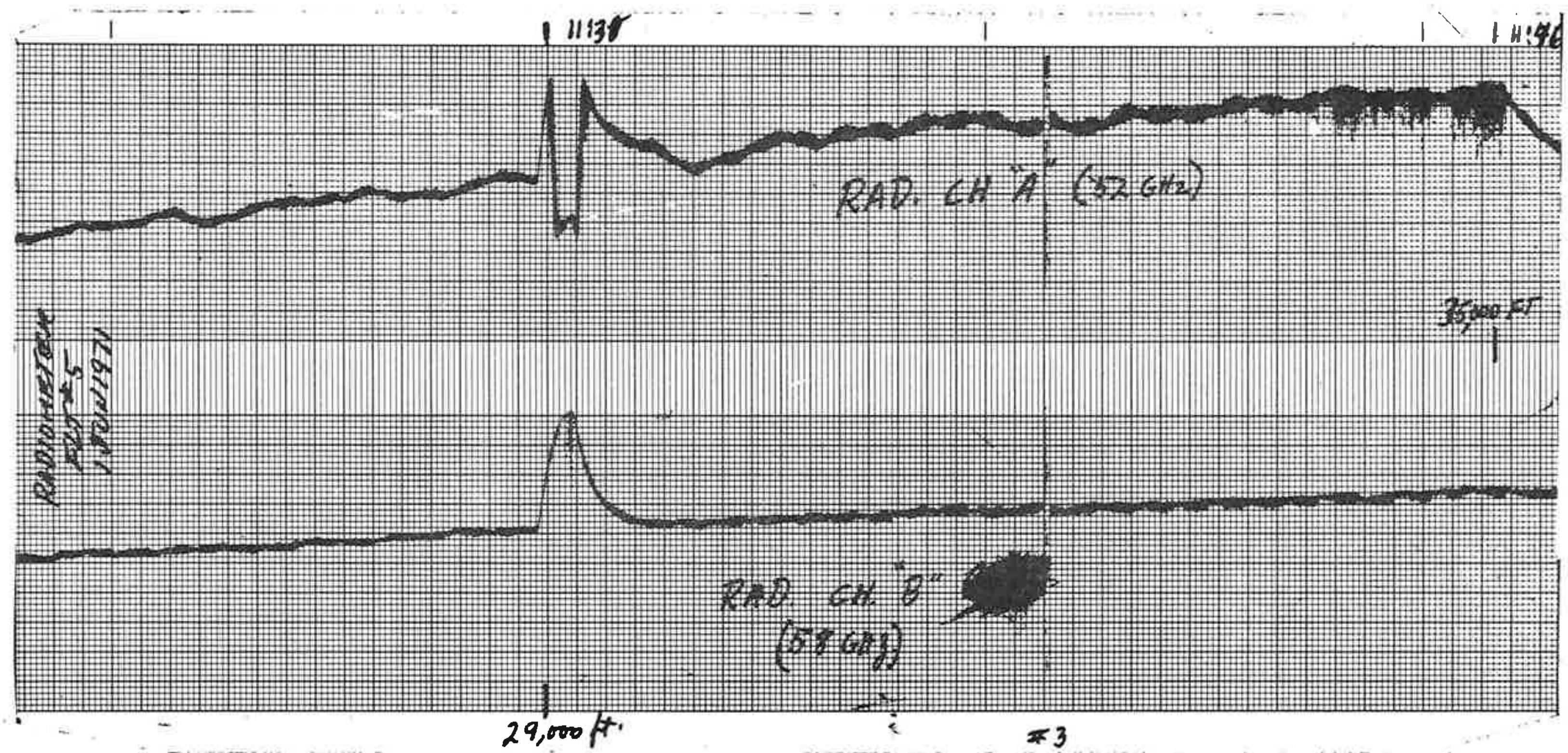


Figure 4. Data Chart Recordings (Flight 5).

2) The seasonal period of the conducted flights, May and June, was not conducive for clear air turbulence search, since CAT appears to be prevalent in subtropical climates. This is borne out from the lack of turbulence forecasted from local weather stations and the Air Force Weather Central.

3) It is reasonable to state that no turbulence was encountered by a review of the acceleration data recorded. The low g-force shown can be attributed to normal aircraft maneuvers, except at the planned 2g pull-up, whereas g-forces in excess of 1.0 can be expected in turbulence.

4) The ability of the radiometric sensor to sense ambient temperature is confirmed by the measurement of lapse rate recorded during climb, descent, and unusual maneuvers of the aircraft during the initial flight.

5) A review of the velocity, temperature, aircraft attitude and altitude parameters indicates proper trends, but that some inaccuracies exist for data correlation. Also, correction of ancillary sensor equipment deficiencies and additional refinement of equipment calibrations are in order for additional flights.

6) It is further concluded that the minimum accumulated flight time and conditions under which the initial flights were performed cannot be considered a true test of the radiometric sensor capability to detect CAT. Future flights need to be conducted in areas of and during forecasted turbulence on an individual basis.

INSTRUMENTATION SYSTEM PACKAGE (FIGURES 5 AND 6)

The concept, design, and final integration of this sensor system package were accomplished as an in-house task and completed December 1970. In anticipation of the limited time available between flights for calibration and repairs during field operations, the limited space available, and the possibility of future use in other aircraft, the sensor system was packaged within an envelope 22 inches wide, 17 inches high, and 34 inches deep. All the sensors (except the outside probe) and electronics are mounted on a single plate with slide rails. The complete package can be removed through the front of the pod by removing four latch bolts and disconnecting two electrical connectors with the pod on or off the aircraft. The system operates as an independent automatic unit. A single master switch in the pilot's compartment controls all the 28 VDC and 400-cycle, 200-watt power from the aircraft electrical system to the sensor system. An additional switch is provided the pilot for controlling the data-receiving function of the tape recorder, and an additional cable provides pilot voice recording. A six-pin connector at the wing tip is the only aircraft electrical interface for operation of the complete system package. The final pre-flight sequence consists of starting aircraft engines, CAT system cockpit switches on, external functional check of CAT sensors, and aircraft departure.

The sensors and electronics contained in the system package are as follows:

1. Dual-channel radiometric sensor - TSC experiment.

2. Airborne tape recorder (Genisco) - consists of 15 recording channels and accepts data signals in the form of voltages which are converted back to flight parameters during the data-reduction process.

3. Time-code generator (Datametrics) - Recorded as real-time for ranging calculations of clear air turbulence. The actual time is set into the TCG at pre-flight in accordance with the pilot's clock.

4. Altimeter transducer (Edcliff) - provides an accurate indication of flight altitude during CAT search and changes thereof during CAT encounters. This unit senses

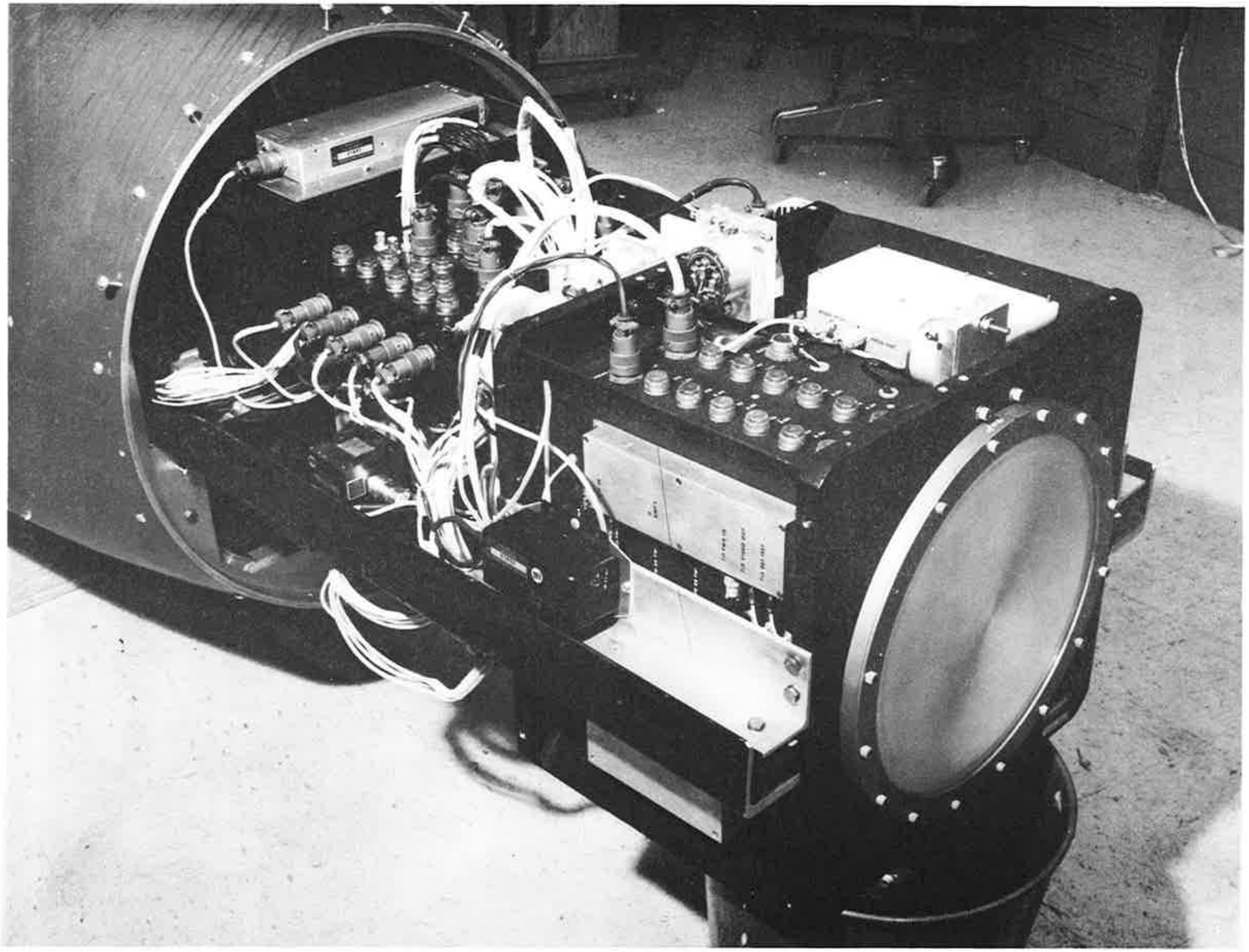


Figure 5. Radiometric Sensor System Package.

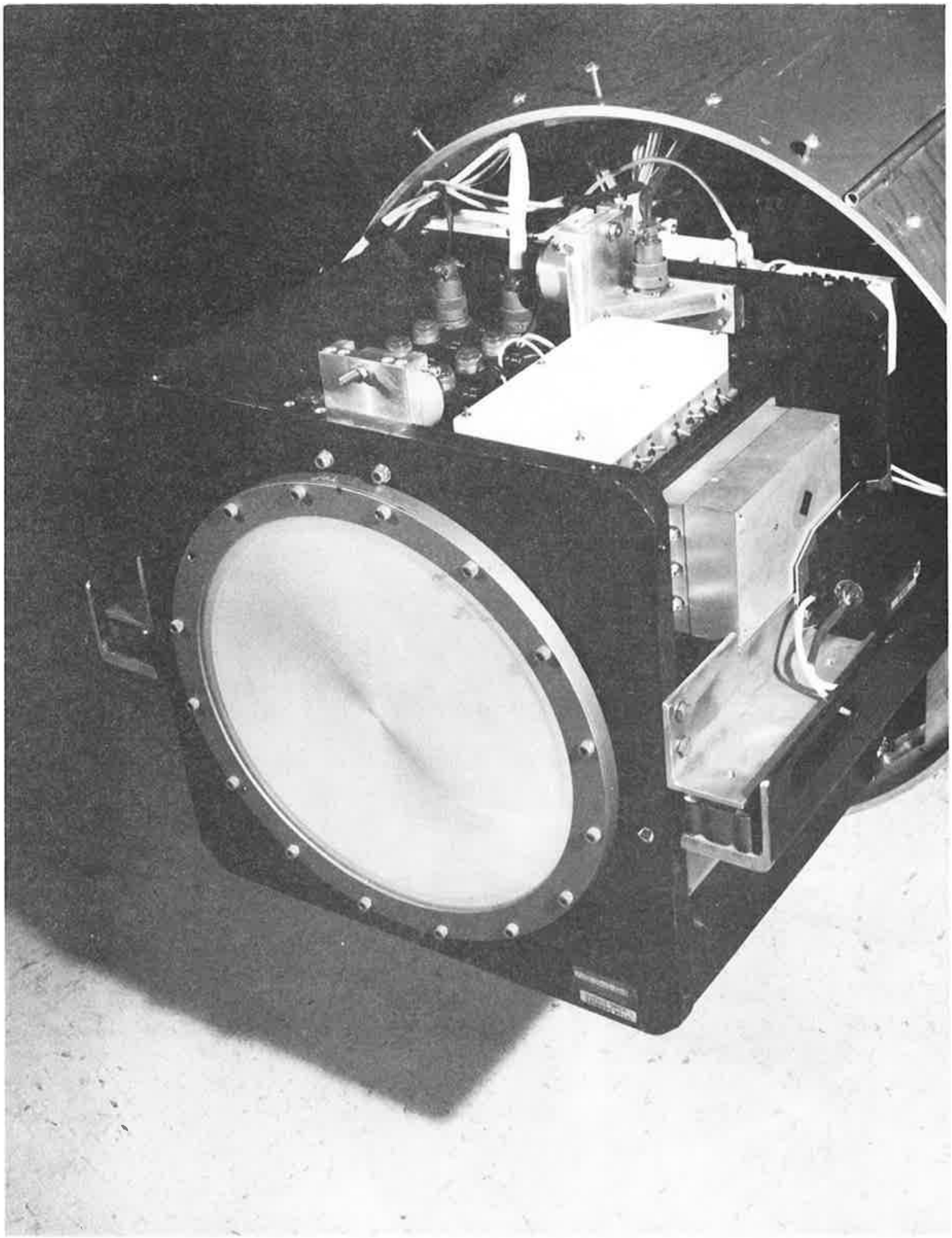


Figure 6. Radiometer Partially Removed from Pod.

atmospheric pressures through a static port located outside the pod. These pressures are converted and recorded as voltage signals on the magnetic tape.

5. Accelerometers (Edcliff) - Three accelerometers are mounted directly on the package for g-force measurement in the vertical, lateral, and thrust direction during clear air turbulence encounters.

6. Vertical gyro (Lear Sigler) - Provides an accurate indication of the CAT sensor attitude in "pitch" and "roll" for small degree changes.

7. Inclinometers (Edcliff) - Provide "pitch" and "roll" data for changes in attitude plus-or-minus 0 to 30 degrees.

8. Thermocouples - One internal thermocouple is used to measure temperature changes in the pod. A second external thermocouple is mounted at the top forward end of the pod to measure ambient temperatures in conjunction with clear air turbulence encounters and is used in the data analysis of the CAT sensor measurements.

9. Velocity probe and electronics (Datametrics) - This probe is external to the pod. It is calibrated for the operating altitude and measures wind speeds and changes thereof. These data provide a means for calculating accurate aircraft airspeed and vertical shear velocities associated with turbulence.

10. Electronic junction box (TSC) - This unit contains the relays, circuit breakers, and electronics. It is also the terminal point for the signals incoming from the sensors that are distributed to the 15-channel tape transport.

Simultaneous meteorological data and ranging information, as well as mechanical changes in the aircraft, are recorded as functions of turbulence severity.

WING-TIP POD MODIFICATION

In order to support the CAT experiment on a flight basis, NASA/Flight Research Center provided and shipped a standard tip tank to TSC for conversion to an instrumentation pod. The pod's overall dimensions are 170 inches long and 32 inches at the largest diameter. The shell originally separated into two parts at a point 36 inches from the forward edge. As a result of modification, the pod assembly now consists of five major subassemblies: the rear shell, front shell, radome, instrument package support structure, and balance weight assembly. Figure 7 shows the complete flight package less the radome. The rear shell modification includes longitudinal braces to prevent skin ripple and houses the counterweights and platform (9.5 feet to the rear) for retaining the original cg 72 inches from the front tip. It is also the main support for the instrument package support structure. The support structure consists of two slide rails mounted on two cross-braced cantilever beams and features exposure of the entire structure and sensor system package when the front shell is removed.

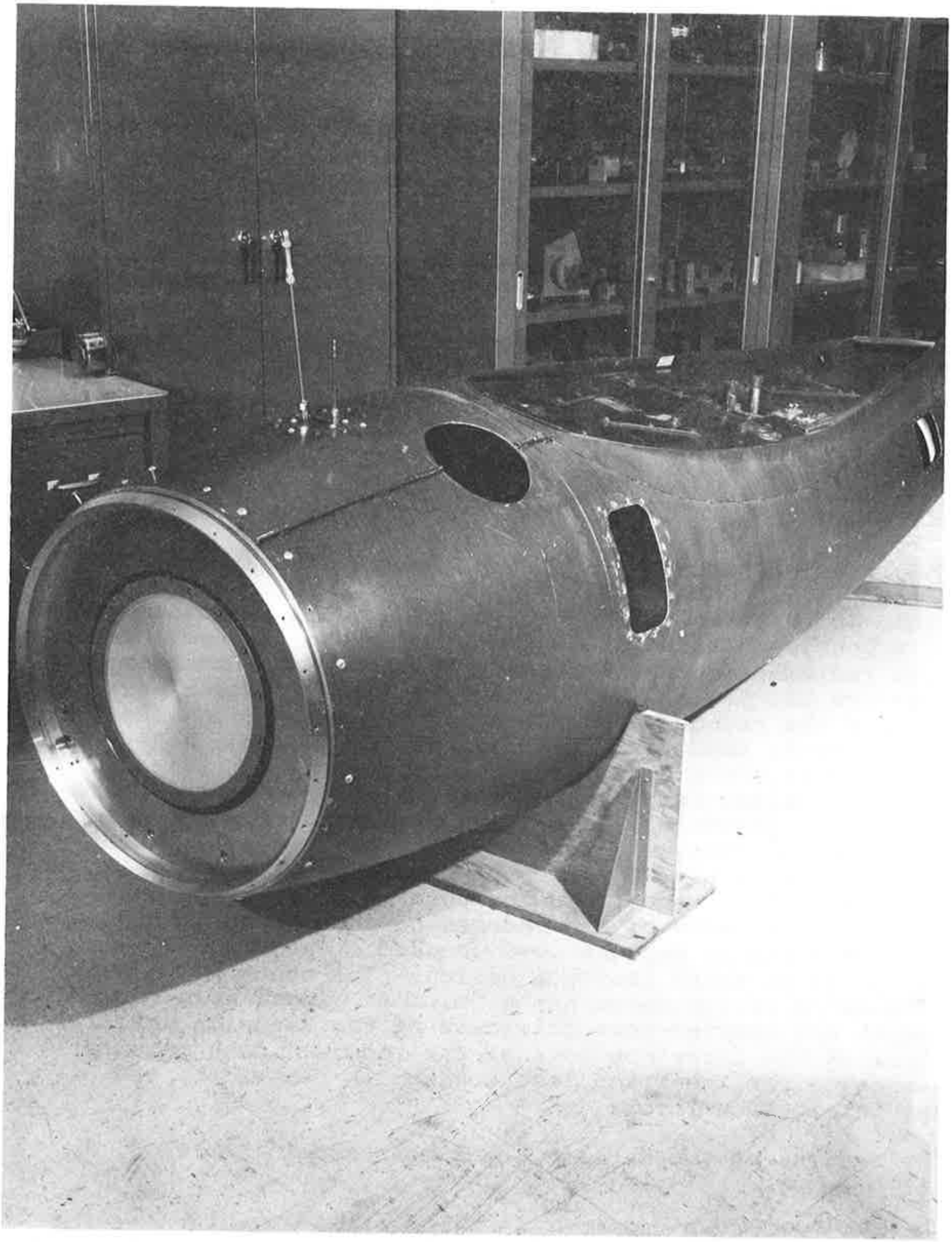


Figure 7. Flight Package with Radome removed.

The front shell provides additional support in flight when bolted in place. It contains a 61-pin external electrical connector at the bottom, wiring for final pre-flight sensor checks, an individual plate for mounting the external temperature and velocity probe, and a slip-type ring for support and quick removal of the radome assembly. The front mating slip ring contains a 0-seal for pressure sealing the pod and a wind-blast bulkhead in the event the radome is shattered during flight. The radome details are covered in a later paragraph.

All of the mechanical and electrical concepts, designs, and working drawings were accomplished by the CAT task group at TSC. Modification of the pod was accomplished by TSC in order to control design features accurately and gain economical advantages in time. The flight package was completed in-house by the CAT Task group February 1, 1971, consuming a total of six months. Performance test of the complete flight package was then completed, and the equipment was prepared for shipment to NASA/FRC prior to February 9, 1971.

RADOME AND ANTENNA TRANSMISSION TEST

The radome-antenna tests at the M.I.T. Antenna Range were completed on September 1, 1970 by TSC personnel. Data were obtained on the transmission losses of a solid laminated radome, a honeycomb structure radome, and the efficiency of the 12-inch radiometric cone antenna. Tests were conducted at frequencies 51, 52, 53, 57, 58, and 59 GHz. A cursory examination of the radome data indicated the loss through the solid radome is about 1/2 dB. The loss through the honeycomb radome is about 1 dB, as predicted by the McMillan Company. McMillan Company manufactured the radome in accordance with TSC design specifications utilizing existing molds. Thus the two radomes were procured at a minimum cost. Radiation patterns of the CAT antenna were taken at the MIT Lincoln Laboratory Antenna Range. The purpose of these tests was to determine the effects of the radomes on the antenna characteristics. Two radome designs were checked. One radome was a .054-inch thick solid laminate design. The other was a honeycomb sandwich design which has a thicker window area but which relies on the quarter-wave thickness of the sandwich material to minimize the insertion loss of the radome. Both radomes were checked for insertion loss, change in beamwidth, and change in sidelobe level.

The results of these tests are summarized in Tables 3, 4, and 5.

Table 3 tabulates the E-Plane and H-Plane beamwidth of the antenna as a function of frequency and also indicates that very

SUMMARY OF PATTERN DATA TAKEN ON CAT DETECTOR ANTENNA AND RADOMES

Table 3

Freq. GHz	E-Plane -3 dB B.W.	H-Plane -3dB B.W.
51	1.7°	1.7 °
52	1.65°	1.6°
53	1.6°	1.55°
57	1.5°	1.5°
58	1.8°	1.75°
59	1.6°	1.6°

Variation of Half-Power Beamwidths with Frequency
(Effect of either radome on half-power beamwidths was negligible at all the frequencies checked)

Table 4

Freq. GHz	w/o Radome (dB below Peak)	E-Plane Side Lobe Levels with .054 Radome (dB below Peak)	with Honeycomb Radome (dB below Peak)
51	35	34	34
52	28	25	25
53	35	31	>35
57	35	35	34
58	35	31	32
59	>30	30	29

Freq. GHz	w/o Radome (dB below Peak)	H-Plane Side Lobe Levels with .054 Radome (dB below Peak)	with Honeycomb Radome (dB below Peak)
51	33	25	33
52	29	29	29
53	34	27	>34
57	34	26	25
58	37	26	30
59	33	>33	>33

Effect of Radomes on Antenna Side Lobe Level

Table 5

Freq. GHz	Attenuation of .054 Solid Laminate Radome (dB)	Attenuation of Honeycomb Sandwich Radome (dB)
51	.60	1.2
52	.35	1.4
53	.80	1.6
57	.45	1.9
58	.60	1.3
59	.40	1.5

Insertion Loss of Radomes

little change occurs in the main beam with either radome. The data in Table 4 show the variation of sidelobe level as a function of frequency and the effect of the radomes. Again, although some variation in sidelobe level is observed, the changes are not too great.

The loss data in Table 5 show the insertion loss of the two radomes as a function of frequency and clearly indicate that the .054 radome is superior electrically to the honeycomb design. This is probably due to the fact that the frequency range over which the resonant window of the honeycomb radome is to be used is too large to be effective. Furthermore, at these frequencies, thickness tolerances and material homogenity tend to lessen the effectiveness of this design.

It had been hoped to measure antenna gain in order to determine antenna efficiency; however, the limited time available precluded the time-consuming precautions and multiple readings required to make meaningful gain measurements at these frequencies.

POD—AIRCRAFT INTERFACE (FIGURES 8-12)

Mating of the pod to the aircraft was accomplished by FRC. The pod, as shown in Figure 8, is attached to the right wing tip by three hang bolts, through the top of the wing, into three pads located in the pod rear shell assembly.

The additional weight of the experimental flight package on the right wing was counterbalanced by installation of the left wing-tip tank on the aircraft. An equivalent weight of glycol and water was used to balance the aircraft.

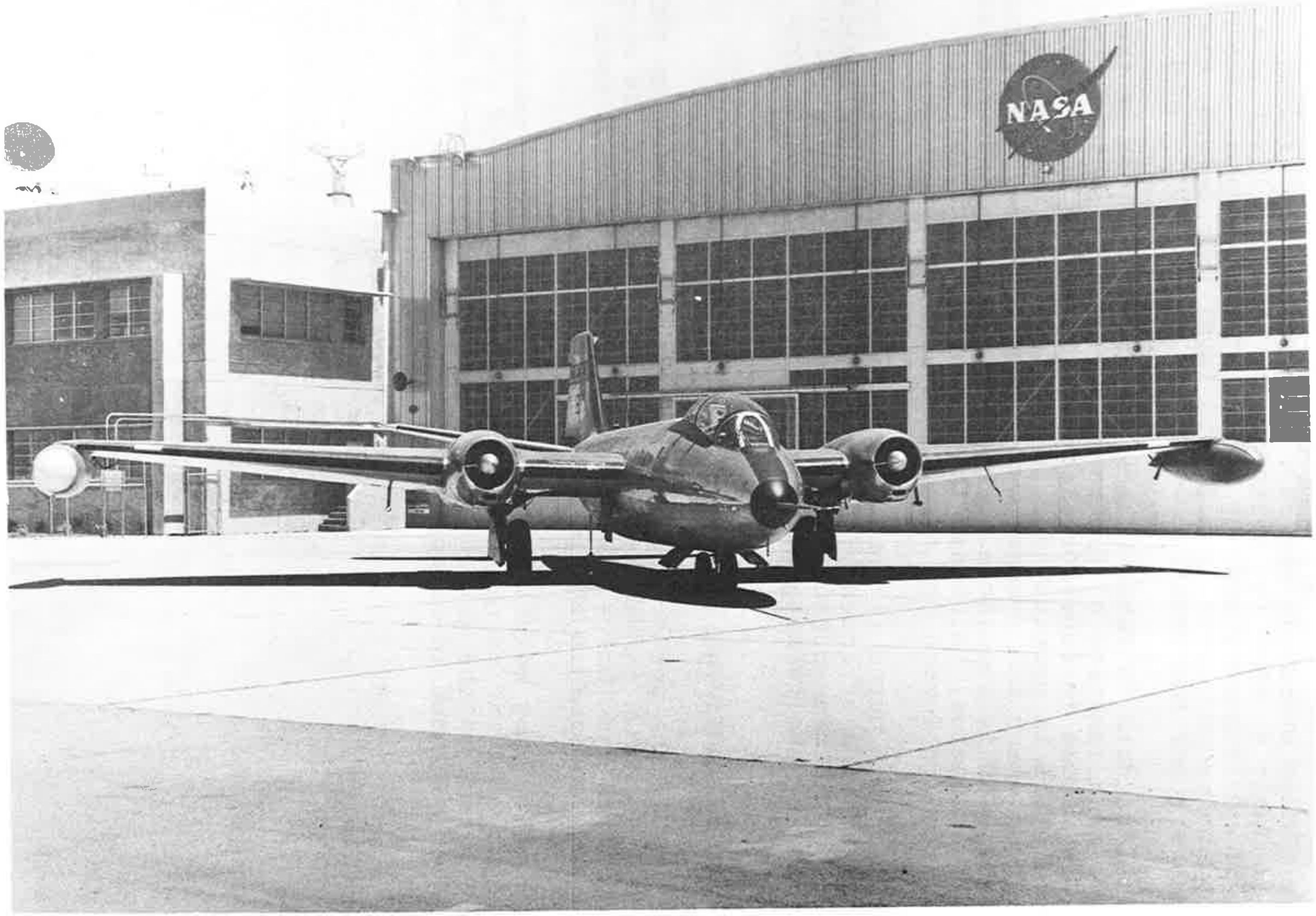


Figure 8. Front view of TSC Pod on right wing tip.

Figure 9. Side view of TSC Pod on B-57 aircraft.

Figure 10. Angle View of TSC Pod on wing tip.

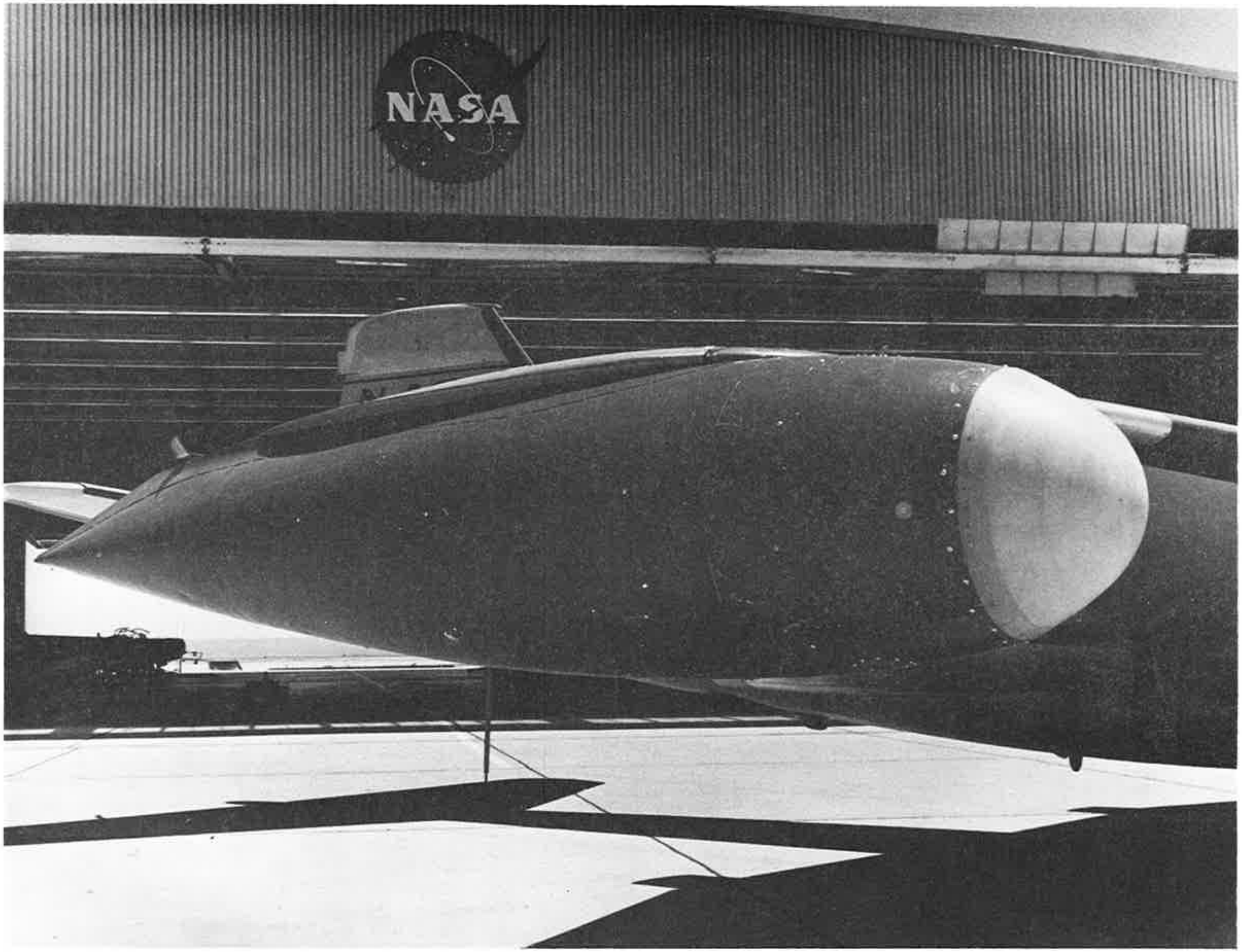


Figure 11. Instrumentation Pod mounted on wing tip.

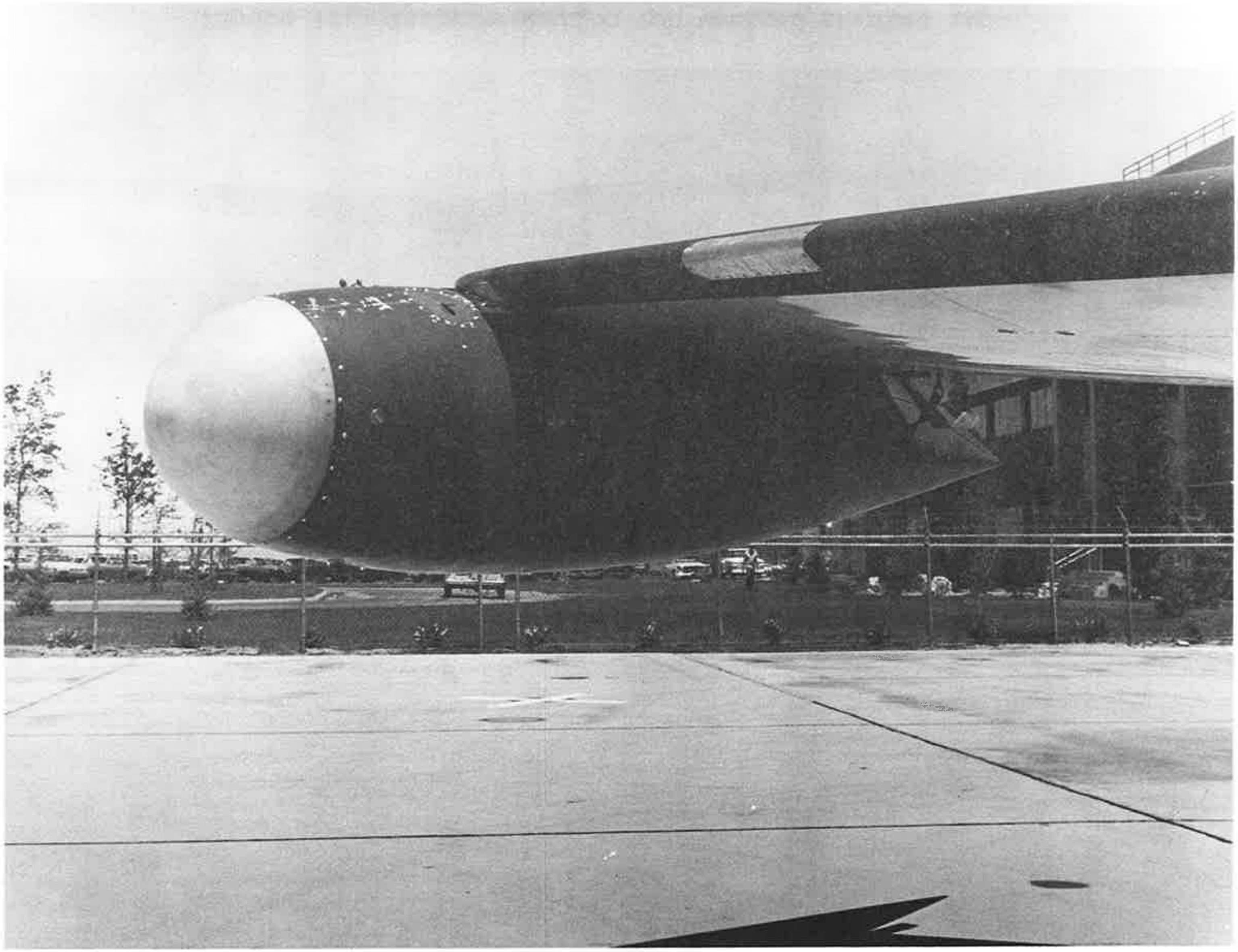


Figure 12. Close-up of TSC package - flight ready.

Flight package weight and balance are as follows:

Right wing pod empty		174.0 lbs.
Instrumentation package	156.0	
Radome assembly	18.0	
Internal support structure	25.5	
Pod pitch (c.g.) balance weight	125.0	
Right pod unbalance----	324.5 lbs.	
Total right wing weight		498.5 lbs.
Left wing-tip tank empty		- 174.0 lbs.
Left wing water-glycol ballast		324.5 lbs.

OPERATING PROCEDURES

A separate document, titled "Operating Procedures for the Clear Air Turbulence Detection System," was generated in preliminary form for use as a guide in the laboratory and flight test operations. Updating and correction of the present rough draft will be performed on a continuing basis during initial flight operations. Completion of the basic instruction is planned for October 1971.

The information presented as procedures include:

1) Flight system package components,

2) Flight system installation and removal (aircraft),

3) Flight system assembly and disassembly,

4) Instrument package assembly and disassembly,

5) Pre-flight functional test,

6) Post-flight functional test,

7 In-laboratory performance test procedure,

8 Data analysis procedure,

9 Flight planning,

10 Pilot operating procedure,

11 Tape recorder operating instructions,

12 Time-code operating instructions,

13 Supporting calibration table and curves, flight and data log forms, and pertinent diagrams.

FLIGHT SCHEDULING (FIGURE 13)

The flight schedule presented reflects the latest changes as of the date shown thereon. It is compiled from verbal FRC information and anticipated DOT/TSC flight planning; therefore, it should not be considered as a firm commitment by NASA/FRC, but rather to provide an overall view of the aircraft availability for a foreseeably short time period.

The controlling function indicates the project having the highest priority at the reporting time. This means that the other flight experiments shown are scheduled and conducted either concurrently or individually depending on the inactivity of the high-priority project. Thus, "tentative" means a planned schedule subject to change. The solid bars on the bar chart indicate a firm future schedule, but the schedule posted may include slippage that occurred due to various instrumentation and flight program delays.

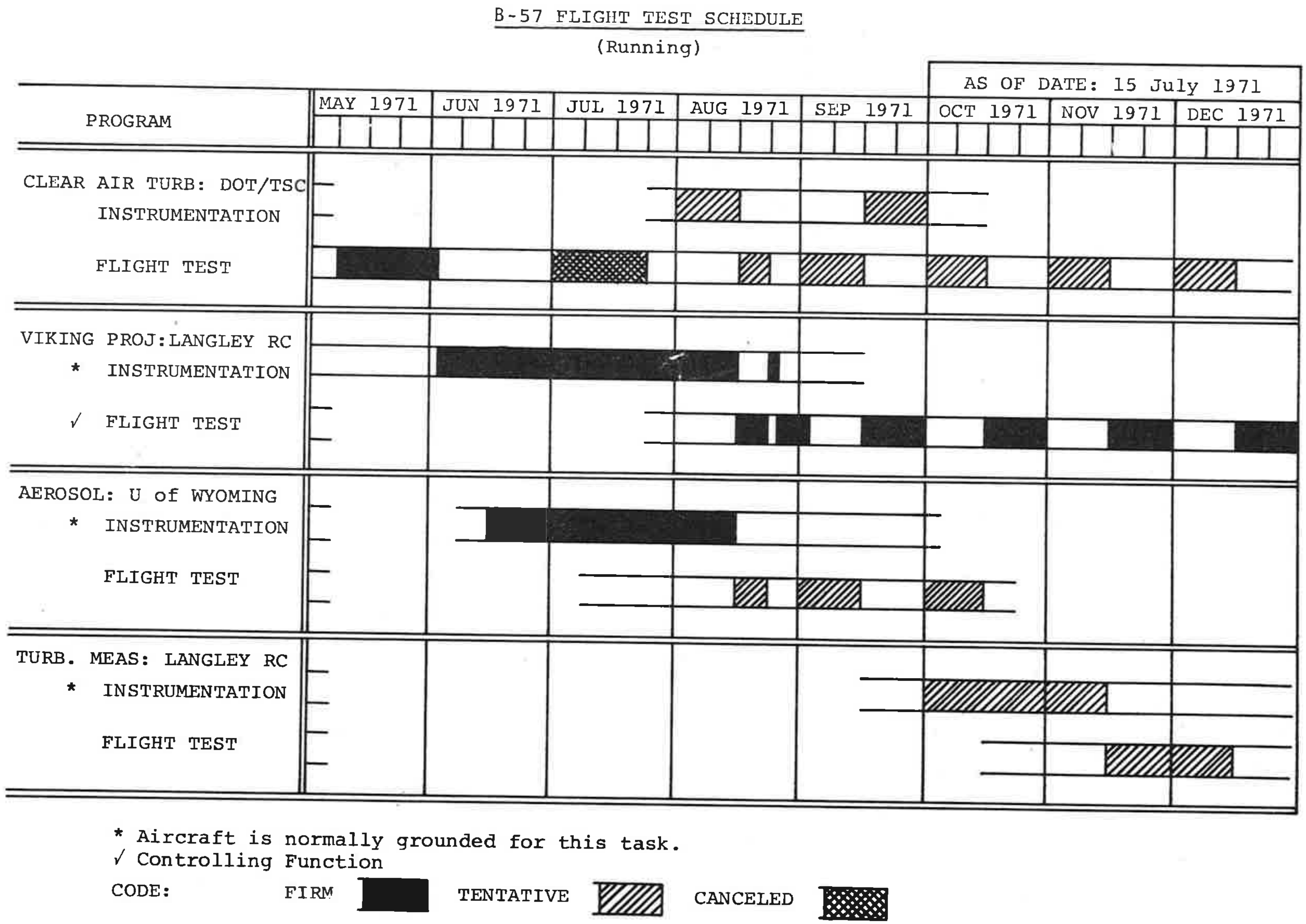


Figure 13. B-57 Flight Test Schedule.

SIGNIFICANT DOCUMENTATION

A paper, entitled "A Dual-Channel 5-Millimeter Radiometric Sensor for Detecting Clear Air Turbulence in the Troposphere," by G. G. Haroules and W. E. Brown, has been submitted to the IEEE Transaction AES. A patent disclosure, entitled "A Method and a Means for Detection of Clear Air Turbulence by a Multi-Frequency Radiometer Operating at Approximately 60 GHz," has been prepared by the TSC patent counsel and is undergoing final examination by the U.S. Patent Office.

User instructions, entitled "Operating Procedures for the CAT Detection Flight System," were prepared at DOT/TSC by G. W. Wagner and W. E. Brown. "Design Drawing, Mechanical and Electrical" also was prepared at DOT/TSC by G. W. Wagner and W. E. Brown.

MILESTONES

See attached milestone schedules

a) For FY 1971-----ST-01 and FA-20

b) For FY 1971-----FA-220

c) For FY 1972-----FA-220

TRANSPORTATION SYSTEMS CENTER

PPA: ST 01 & FA20

TITLE: LONG RANGE CLEAR AIR TURBULENCE DETECTION

FUNDING:

BRIEF PROJECT DESCRIPTION:

TASK

Equipment Acquisition
Radome-Antenna Test and Data-Reduction

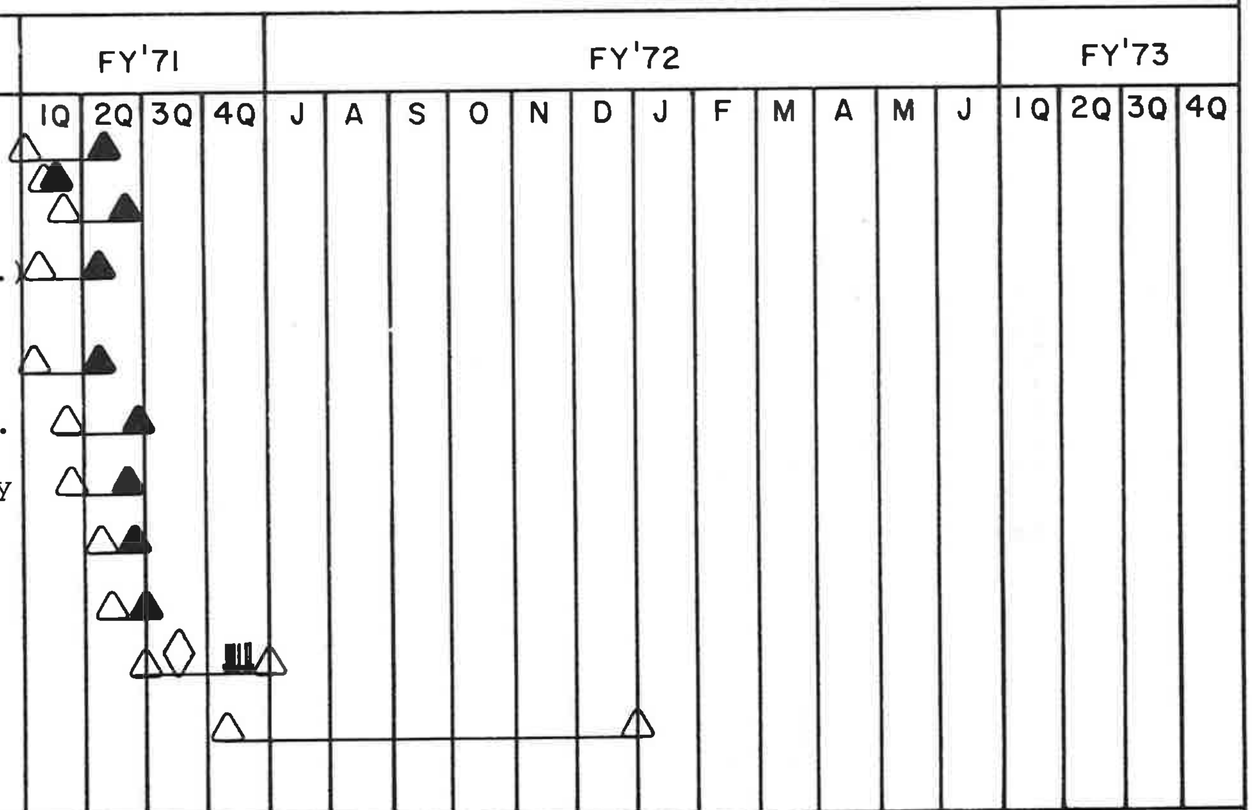
Aircraft Modification (Elect.)

POD Modification
a) Pod shell and radome
b) Pod internal support structure design and fab.
c) Sensor system package design, fab. and assembly
d) Sensor system electrical interface and checkout

POD Package Completion

Flight Program at NASA-FRC

Advanced Flight Program



LEGEND:
△ SCHEDULED
▲ ACCOMPLISHED
◇ MILESTONE SLIPPAGE

REMARKS:
Additions this period:
◇ Actual start of flight operations
↓ Participating flights accomplished

TRANSPORTATION SYSTEMS CENTER

PPA: FA-220 | **TITLE:** LONG RANGE CLEAR AIR TURBULENCE DETECTION | **FUNDING:** $200K

BRIEF PROJECT DESCRIPTION: The scope of the Long Range Clear Air Turbulence Detection is to evaluate and develop a microwave radiometric technique for sensing and detecting clear air turbulence.

TASK	FY'71				FY'72												FY'73			
	1Q	2Q	3Q	4Q	J	A	S	O	N	D	J	F	M	A	M	J	1Q	2Q	3Q	4Q
Install radiometric sensor in wing pod and perform laboratory tests using the flight recording equipment and laboratory test cables.			▲																	
Install the wing pod, radiometric sensor, auxiliary meteorological sensors and recording equipment and perform preflight tests to assure aircraft sensor interfaces.				▲																
Update all aircraft drawings to reflect flight configuration status.				▲																
Perform initial pre-flight tests to validate flight procedures and program to be used for collecting data.				▲▲																
Conduct preliminary flight tests to assure sensing of phenomenon.				▲▲																

LEGEND:
- △ SCHEDULED
- ▲ ACCOMPLISHED
- ◇ MILESTONE SLIPPAGE

REMARKS: This program was supported in FY-71 as ST-01 with the same title and objective.

PPA: FA-220 | **TITLE:** LONG RANGE CLEAR AIR TURBULENCE DETECTION | **FUNDING:** $200K

BRIEF PROJECT DESCRIPTION: The scope of the Long Range Clear Air Turbulence Detection is to evaluate and develop a microwave radiometric technique for sensing and detecting clear air turbulence.

TASK	FY'71				FY'72												FY'73			
	1Q	2Q	3Q	4Q	J	A	S	O	N	D	J	F	M	A	M	J	1Q	2Q	3Q	4Q
Conduct flight tests to A. Determine range sensitivity, B. Determine range granularity, C. Determine false alarm rate and correlate with phenomenon, D. Measure atmospheric parameters associated/ with CAT.					▲											△ PASSIVE SYSTEM CHARACTERISTICS DETERMINED				
Analyze data and determine adequacy of radiometric sensor to sense and detect CAT.											△ DATA		△ ANALYSIS COMPLETED							
Review current sensor design and recommend future design improvements to sensor.												△ IMPROVEMENT TO SENSOR DESIGN				△ COMPLETED				
Final Report													△			△ REPORT				

LEGEND:
△ SCHEDULED
▲ ACCOMPLISHED
◇ MILESTONE SLIPPAGE

REMARKS:

APPENDIX A

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
Flight Research Center
Flight Request

Flight No. 35 (DOT #4) Aircraft B-57B #809 Date of Request 24 May 71

Est. T/O Time ________ Date of Flight 26 May 71

Purpose of Flight: System Shakedown of Dept. of Transportation CAT Experiment

Airplane Configuration: Standard B-57B aircraft with tip tanks. RH tip tank modified for DOT CAT Experiment.

Engine Identification: ________ Take-off Weight, lbs. 41,000

Take-off C.G. Position, %MAC 27.5 Flight Range 27.5 to 27.7

REQUIREMENTS:

1. NASA FRC Radar (FPS 19) -- X --
2. NASA Ely Radar (FPQ 6) ________
3. Plotting Board Map ________
   a. Type or Scale ________
   b. To be furnished by engr. ________
4. USAF Radar (FPS 16) ________
5. Plotting Board Map ________
6. USAF Askania Radar ________
7. TACDAC Tape (NASA Radars) ________
   a. GE-225 Data; Formated Tape ___
      List Out ________
   b. IBM Radar Program List Out ___
8. TACDAC Tape (USAF Radar) ________
9. Weather Balloon ________
10. T/M Frequency ________
11. UHF Frequency NASA Test (270.3)
12. VHF Frequency ________
13. HF Frequency ________
14. Chase/Target Airplane, Type:
    Take-off ____, Landing ____, Photo ____,
    Other ________
15. Pressure Suit Van ________
16. Ground Voice Recorder X
17. Biomed Instrumentation ________
18. Other (Specify) ________

Crew:	Hugh Jackson	Ext.	201
Station Communicator:	Bob Baron	Ext.	271
Project Engineer:	Mike Groen	Ext.	754
Research Engineer:	Mike Groen: George Wagner (DOT)	Ext.	754
Instrumentation Engineer:	Jack Albers C. C.	Ext.	361
Operations Engineer:	Bob Baron	Ext.	271

APPROVALS: Chief Research Projects Office ________

Director of Research ________

Director of Flight Operations ________

Preliminary Flight Plan Attached

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Flight Research Center

Flight Plan

Flight No. 4 (DOT) FRC #35 Aircraft B-57B #809 Date of Flight 26 May 71

PRIOR TO PILOT ENTRY:

Ground Power ON
DOT Experiment Power ON (Do not cycle DOT Experiment Power switch).

AFTER PILOT ENTRY:

Cockpit time check & outside temp (on intercom OK).

PRIOR TO TAXI:

Time check (on intercom OK radio).

TAKEOFF:

Time at start of toll and heading.

CLIMBOUT:

Report each 5,000 ft.; time, outside temp, heading, airspeed, and rate of climb.

FLIGHT:

(1) Stabilize altitude at 10,000 $\pm$ 5,000 feet for 10 min.

(2) Climb to 30,000 $\pm$ 5,000 feet at 6^{o} climb angle.

(3) Stabilize at 30,000 $\pm$ 5,000 feet for 10 minutes, holding constant heading.

(4) Using attitude indicator set on $+5^{o}$, $+10^{o}$, $+15^{o}$ holding attitude for 10 sec. Repeat for neg. settings.

(5) Using attitude indicator set on 2^{o}, right sideslip for 10 sec. Repeat for left settings.

(6) Turn right 90^{o} azimuth and stabilize for 5 min.

(7) Turn right 90^{o} azimuth and stabilize for 5 min.

(8) Search for CAT as time permits.

(9) Descendto 20,000 $\pm$ 5,000 feet altitude at angle similar to climb angle 6^{o}.

(10) Stabilize at 20,000 $\pm$ 5,000 feet altitude for 5 min. holding heading constant.

(11) Search for CAT.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Flight Research Center

Flight Plan

Flight No. 4 (DOT) FRC 35 Aircraft B-57B #809 Date of Flight 26 May 71

(12) Descend to 10,000 ± 5,000 feet altitude at angle similar to climb angle 6°. Make a 2G pullout.

(13) Stabilize at 10,000 ± 5,000 feet altitude for 5 minutes holding heading constant.

(14) Search for CAT.

(15) Return to base and land.

NOTE: Pilots voice is recorded on data tape in right-hand wing tip tank and is used for data identification and data work-up. Data tape has 4 hour capacity.

Pilot should say - Time, run number, date, location, altitude, heading, airspeed, fuel, attitude indicator reading, weather conditions.

PILOT INSTRUCTIONS
CAT PROJECT (DOT)

Voice Reports on Intercom or Radio

1. BEFORE START: Cockpit time and outside air temp.
2. BEFORE TAXI: Time
3. AT TAKEOFF: Time and runway heading.
4. CLIMBOUT: Report at each 5,000 ft; time, heading, airspeed, rate of climb and outside temp.
5. FLIGHT: (changes in)
   Level: time, heading, altitude, airspeed
   Descent: time, heading, airspeed, rate of descent
6. TURBULENCE ENCOUNTERS: Time, heading, altitude, airspeed, outside temp. and position report.
7. HEADING CHANGES: Report time, altitude, and new heading.
8. LANDING: Traffic pattern (downwind leg)
   Report: time, altitude, airspeed, and estimate angle of attack if possible.
9. TAXI IN: Report time. Do not shutdown until DOT check.

APPENDIX B

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
Flight Research Center
Flight Request

Flight No. 36 (DOT #5) Aircraft B-57 #809 Date of Request 6/1/71
Date of Flight 6/1/71
Est. T/O Time ____
Purpose of Flight: Search for clear air turbulence for DOT

Airplane Configuration: Standard B-57B aircraft with tip tanks. RH tip tank modified for DOT CAT experiment.
Engine Identification: ____ Take-off Weight, lbs. 41,000
Take-off C.G. Position, %MAC 27.5 Flight Range 27.5 to 27.7

REQUIREMENTS:

1. NASA FRC Radar (FPS 19) ____
2. NASA Ely Radar (FPQ 6) ____
3. Plotting Board Map ____
   a. Type or Scale ____
   b. To be furnished by engr. ____
4. USAF Radar (FPS 16) ____
5. Plotting Board Map ____
6. USAF Askania Radar ____
7. TACDAC Tape (NASA Radars) ____
   a. GE-225 Data; Formated Tape ____
      List Out ____
   b. IBM Radar Program List Out ____
8. TACDAC Tape (USAF Radar) ____
9. Weather Balloon ____
10. T/M Frequency ____
11. UHF Frequency NASA Test 270.3
12. VHF Frequency ____
13. HF Frequency ____
14. Chase/Target Airplane, Type:
    Take-off ____, Landing ____, Photo ____,
    Other ____
15. Pressure Suit Van ____
16. Ground Voice Recorder ____
17. Biomed Instrumentation ____
18. Other (Specify) ____

Crew: ____ Ext. ____
Station Communicator: Bob Baron Ext. 271
Project Engineer: Mike Groen Ext. 754
Research Engineer: Mike Groen, George Wagner (DOT) Ext. 754
Instrumentation Engineer: Jack Albers C. C. Ext. 361
Operations Engineer: Bob Baron Ext. 271

APPROVALS: Chief Research Projects Office ____
Director of Research ____
Director of Flight Operations ____

*Preliminary Flight Plan Attached

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Flight Research Center

Flight Plan

Flight No. 36 (DOT #5) Aircraft B-57 #809 Date of Flight 6/1/71

PRIOR TO PILOT ENTRY: Ground Power ON
DOT experiment power ON (Do not cycle DOT experiment power sw).

AFTER PILOT ENTRY: Cockpit time check & outside temp. (on intercom).

PRIOR TO TAXI: Time check (on intercom).

TAKEOFF: Time at start of T.O. and heading.

CLIMBOUT: Report each 5,000 ft; time, outside temp, heading, airspeed, and rate of climb on intercom.

FLIGHT:

(1) Climb to 30,000 $\pm$ 5,000 feet and report at each 5,000 ft; time, heading, airspeed, rate of climb and outside temp.

(2) Stabilize altitude at 30,000 $\pm$ 5000 feet and maintain straight and level flight as condition permits. Airspeed may vary to hold level flight condition.

(3) Proceed NORTH to the Mt. Whitney area and search for CAT as flight time permits. Pilot to use own discretion for CAT search according to available weather or turbulence reports, and location of same.

(4) If CAT is encountered report time, altitude, location, outside temp, airspeed and heading, then flying the following pattern after passing thru turbulence:

(a) Outbound heading for 5 minutes
(b) 180^{o} turn then fly 10 minutes on an inbound/outbound heading
(c) 180^{o} turn then 5 minutes inbound
(d) 90^{o} left turn then fly 5 minutes outbound
(e) 180^{o} turn then fly 5 minutes inbound
(f) 45^{o} left turn then fly 5 minutes outbound
(g) 180^{o} turn then fly 6 minutes inbound
(h) return to base. (Run additional passes at 20,000 ft if time permits).

NOTE: Report all compass heading, time, and any altitude changes on intercom.

(5) If CAT is not encountered at 30,000 feet after one hour then proceed to 20,000 or 10,000 feet at pilot's discretion and search for CAT or troughs. When turbulence is encountered at the lower altitude, run the pattern in part 4 above or a part thereof as remaining flight time permits.

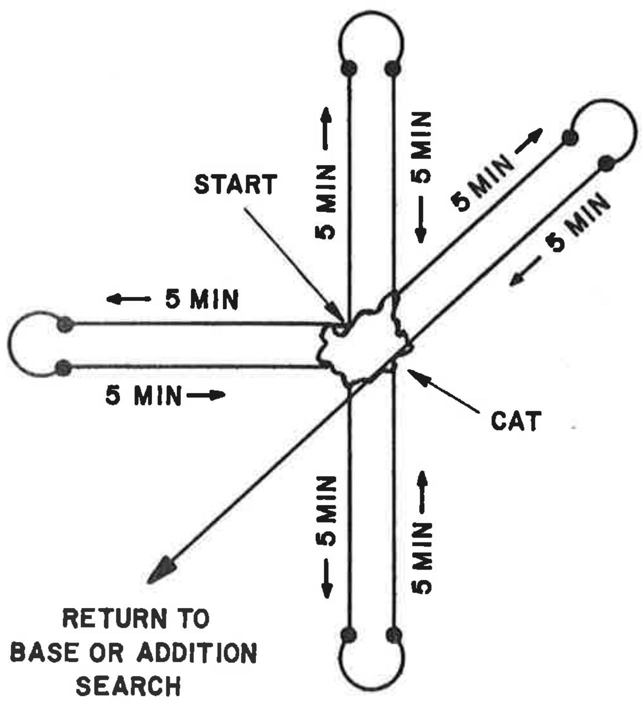
(6) Returning to base - report time and altitude at end of search on intercom.

(7) Landing: Downwind leg - report time and outside temp.

(8) Taxi in & Park: Do not shut down engines until DOT personnel checks exper.

(9) Shutdown: Report time at engine cutoff.

POSTFLIGHT: DOT personnel will turnoff exp. main power switches.



	SEQUENCE	
	CAT ENCOUNTER	
	5 MIN. OUTBOUND	
	180° TURN	
	5 MIN. INBOUND	SAME HEADING
	5 MIN. OUTBOUND	SAME HEADING
	180° TURN	
	5 MIN. INBOUND	
	90° LEFT TURN	
	5 MIN. OUTBOUND	
	180° TURN	
	5 MIN. INBOUND	
	45° LEFT TURN	
	5 MIN. OUTBOUND	
	180° TURN	
	6 MIN. INBOUND	
	END OF PATTERN	

Figure 14 FLIGHT PATTERN AFTER CAT ENCOUNTER

APPENDIX C

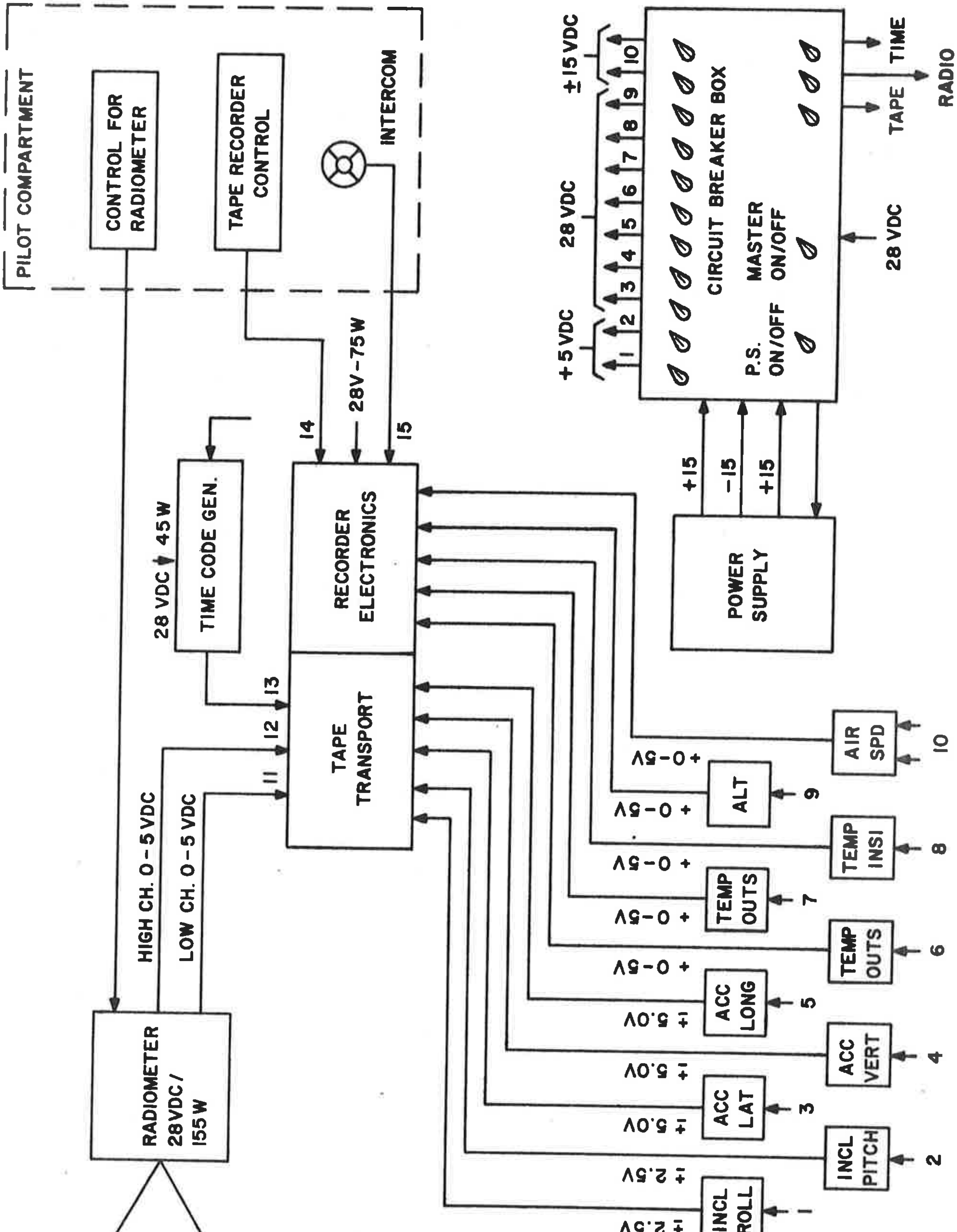


Figure 15. C.A.T. Sensor System Instrumentation Schematic.

ACKNOWLEDGMENT

We wish to recognize the technical efforts of Charles Dunn, George Hollenborg, James Reardon and Paul Podlesny. The teamwork and extra assistance performed by these individuals towards completing the mechanical and electronic integration of the C.A.T. Sensor System Package was indeed instrumental in an earlier flight test program for Clear Air Turbulence Detection.

We also want to acknowledge the coordination and assistance provided by all the NASA/Flight Research Center personnel associated with the flight program phase at Edwards, California.

The authors are indebted to Mr. L. W. Robets and Mr. C. M. Veronda at the Transportation Systems Center as well as Mr. James Muncy of the Federal Aviation Agency for their support and encouragement of this work.