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CLEAR AIR TURBULENCE RADIOMETRIC DETECTION PROGRAM

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FINAL REPORT

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16. Abstract

The report presents the accomplishments of the Clear Air Turbulence Detection Program for the Period July 1, 1971 to June 30, 1972. The experimental effort during this time period was devoted mainly to the flight test program, acquisition of flight data and evaluation of flight data obtained. The program established the ability of the DOT/FAA detection system to sense turbulence and verify the encounter by means of other on-board atmospheric sensors. The total of 15 flights represents 31 flight hours and 26 hours of data tape. Eight of the turbulence encounters reported during these flights are considered significant and ranged from moderate to severe. All test flights were conducted locally (within 350 miles) from NASA/Flight Research Center, Edwards, California.

Instrumentation, supporting hardware and interfaces are briefly reviewed. Improvements to the measurement technique are also presented.

Included are curves, tables and comments which support the events during particular flights where the data indicates changes in atmospheric conditions were sensed before and during turbulence encounters. The conclusions emphasize the need for additional flight tests that are coordinated with meteorological predictions of turbulence conditions in the moderate to severe classifications.

Operational experience gained with each flight allowed problems in equipment functions and data evaluation to be assessed and corrected so as to improve the "follow-on" flights that were conducted. Design improvements are recommended for existing and future sensor systems as well as use of more efficient methods of data reduction as a result of this experience.

A continuation of the flight test program is planned for the coming year by FAA.

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PREFACE

This is the second annual report on the DOT/FAA sponsored, "Clear Air Turbulence Detection" program. The emphasis was on flight tests for fiscal year 1972 and was conducted by DOT/Transportation Systems Center personnel with aircraft support provided by NASA/ Flight Research Center at Edwards Air Force Base, California.

The primary purpose of this report is to present the flight tests accomplishments and the resulting data analysis. The supporting information includes a brief review of previous activities (with some revisions) to reduce the need for reference to the FY'71 annual report.

The authors are indebted to Mr. James Muncy of the Federal Aviation Administration and Mr. Harold Coleman of DOT/OST as well as Mr. L. W. Roberts and Mr. C. M. Veronda at the Transportation Systems Center for their guidance, continuous support, and encouragement of this work.

Special acknowledgements are due for the coordination and assistance provided by the NASA/Flight Research Center personnel associated with the flight program at Edwards, California. In particular, Mike Groen for coordinating flight test and planning, Jack Ehrenberger for weather studies and CAT predictions, test pilots Don Mallick, Fitz Fulton and Einar Enevoldson for their interest and cooperation in flying the test mission, Robert Boyd, Aircraft Maintenance Chief and his associates and Donald Singer and his associates in the Flight Instrumentation Lab for their most helpful assistance and cooperation during ground operations and flight preparations. We also wish to recognize the technical efforts of Paul Podlesny of DOT/TSC for his assistance and performance at both DOT/TSC and the NASA/FRC test site. We also wish to thank William Thompson and Mrs. Paula Brooks of DOT/TSC for their efforts in the preparation of this report.

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1. INTRODUCTION

A recent report by the National Transportation Safety Board (NTSB) entitled 'Study of Lessons to be Learned from Accidents Attributed to Turbulence'[1] has summarized the main lessons learned from turbulence-involved accidents. In eight points, the report briefly concludes that turbulence is one of the major in-flight meteorological problems. The NTSB report also states that a considerable improvement is needed in clear air turbulence (CAT) forecasting and that CAT detection systems both ground based and airborne are needed.

Limited effort has been attempted in development of an operational CAT detection system using various known sensing techniques.

Such techniques have included radars,[2] lasers,[3] long-range optical systems and non-electromagnetic methods such as static air temperature monitors or barometric pressure variation monitors. To date, however, CAT detection and an advanced warning by these methods are still in the exploratory or test stages.

Two significant parameters that recently have been found to be associated with turbulence in clear air are a marked change in atmospheric temperature and a vertical wind shear. However, the lack of exact data on vertical temperature gradients and wind shears support the requirement for the careful measurement of those meteorological parameters that correlate the temperature anomalies, the atmospheric composition and wind shears associated with turbulent regions known as CAT.

The anticipated severity of the hazards experienced by present day operational aircraft associated with the meteorological phenomenon described as clear air turbulence focused increased attention with the advent of high altitude/high speed aircraft to not only the problem of sensing and detecting these anomalies, but its correlation with other known physical parameters of the atmosphere.

In view of the requirement to develop a CAT detection system based on avoidance technology, a Dual Channel Radiometric Sensor was developed in the Electromagnetic Technology Division of the DOT/Transportation Systems Center at Cambridge, Massachusetts. Technological breakthroughs and the development of critical components for the construction of the dual channel millimeter sensor had to be accomplished before an instrument capable of withstanding the rigors of an aircraft environment could be attempted.

Some of these breakthroughs were: a) common antenna and calibration circuitry at a frequency of 60 GHz; b) development of an absolute temperature mode for instrument stability, improved detection capability, and measurement flexibility over wide dynamic ranges; c) development of a broadband four-port Faraday rotator as the basic modulator for multichannel capability in the measurement of range; d) development of separate local oscillators to meet differential volume absorption coefficient requirements at operating frequencies; e) development of a beam switching technique for the measurement of azimuth and the avoidance of the turbulence region and f) a simple pilot control box and operating console coupled with the lightweight low power requirements and small volume demanded by aircraft.

2. MEASUREMENT TECHNIQUE

The 60 GHz radiometer CAT sensor is a 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 in the detection of atmospheric temperature anomalies along the horizontal forward flight path of an aircraft at flight altitudes. The radiometer is a complete sensor system consisting of two radiometric receivers packaged integrally 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 ±1 GHz about their nominal operating frequencies.

The radiometric modes of operation are modified absolute-temperature modes.[4] 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 R.F. (Radio Frequency) 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. A simplified illustration of detecting temperature anomalies forward of an aircraft at high altitude is shown in Figure 2-1a.

The ability to detect temperature anomalies at a wavelength of 5mm. is predicated on the differential atmospheric absorption coefficients which are available over a relatively small frequency range near 60 GHz. The large dynamic range of the atmospheric absorption coefficient in this portion of the spectrum is associated with the resonant line profile characteristics of molecular atmospheric oxygen. The intensity and range of an atmospheric temperature anomaly along the forward flight path of an aircraft is sensed at two or more operating frequencies selected to provide atmospheric absorption coefficients at the flight altitude in the range from 0.1 to 1.0 dB per kilometer. Thus, the channel with the high attenuation value (58 GHz) will observe the temperature abnormally at a later time than the channel (52 GHz) with the lesser attenuation coefficient, that is, when the aircraft reaches a range closer to the CAT. A typical model of the received signals, in relation to Figure 2-1a, is provided in an expanded form in Figure 2-1b.

Toward the CAT zone, the radiometric temperature profiles diverge from each other and the divergence is more pronounced at the frequencies of lesser absorption as expected. Another indication is the appearance of a change in slope of the radiometric profile.

From foregoing discussion of the basic concept, it is apparent that the signature of an atmospheric temperature anomaly takes the form of a difference temperature between the minimum of two frequencies of operation as the function of range. It should be noted that variations in the flight altitude may lead to the detection of temperature differences by both channels; however, these temperature differences will normally be associated with ambient temperature changes as the function of flight altitude. If there is no anomalous temperature region, the output indication from both channels will be the same even though they may both change with time. Thus the base line temperature is considered constant. The most important feature in preflight adjustments is setting the system gain in both channels with an equivalent output as obtained from either channel for a common input temperature difference. Analysis of the observed data then takes the form of measured temperature differences between the two channels of operation as a function of time (range).

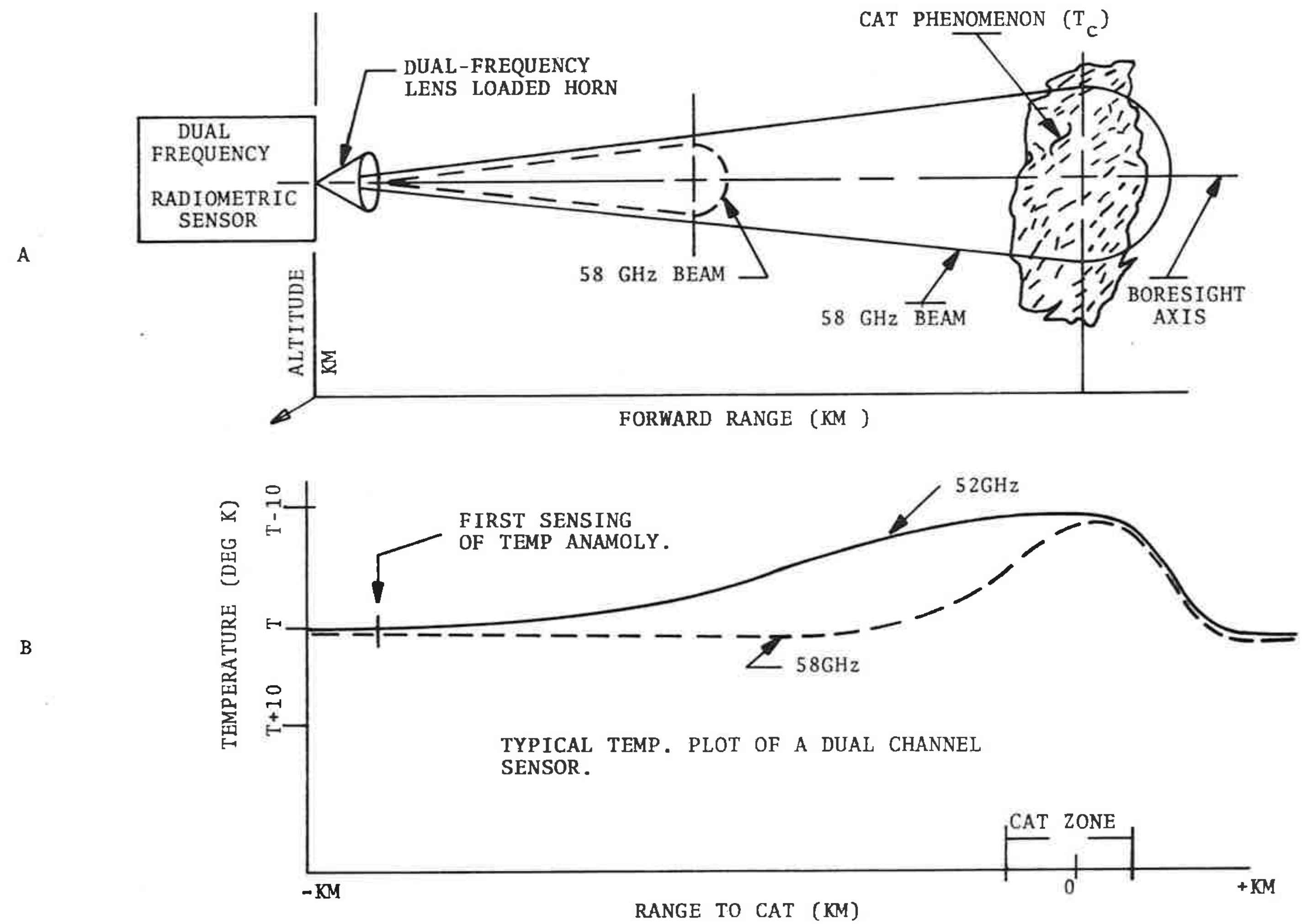


Figure 2-1. Meteorological Phenomenon as Sensed by Dual Frequency Radiometer

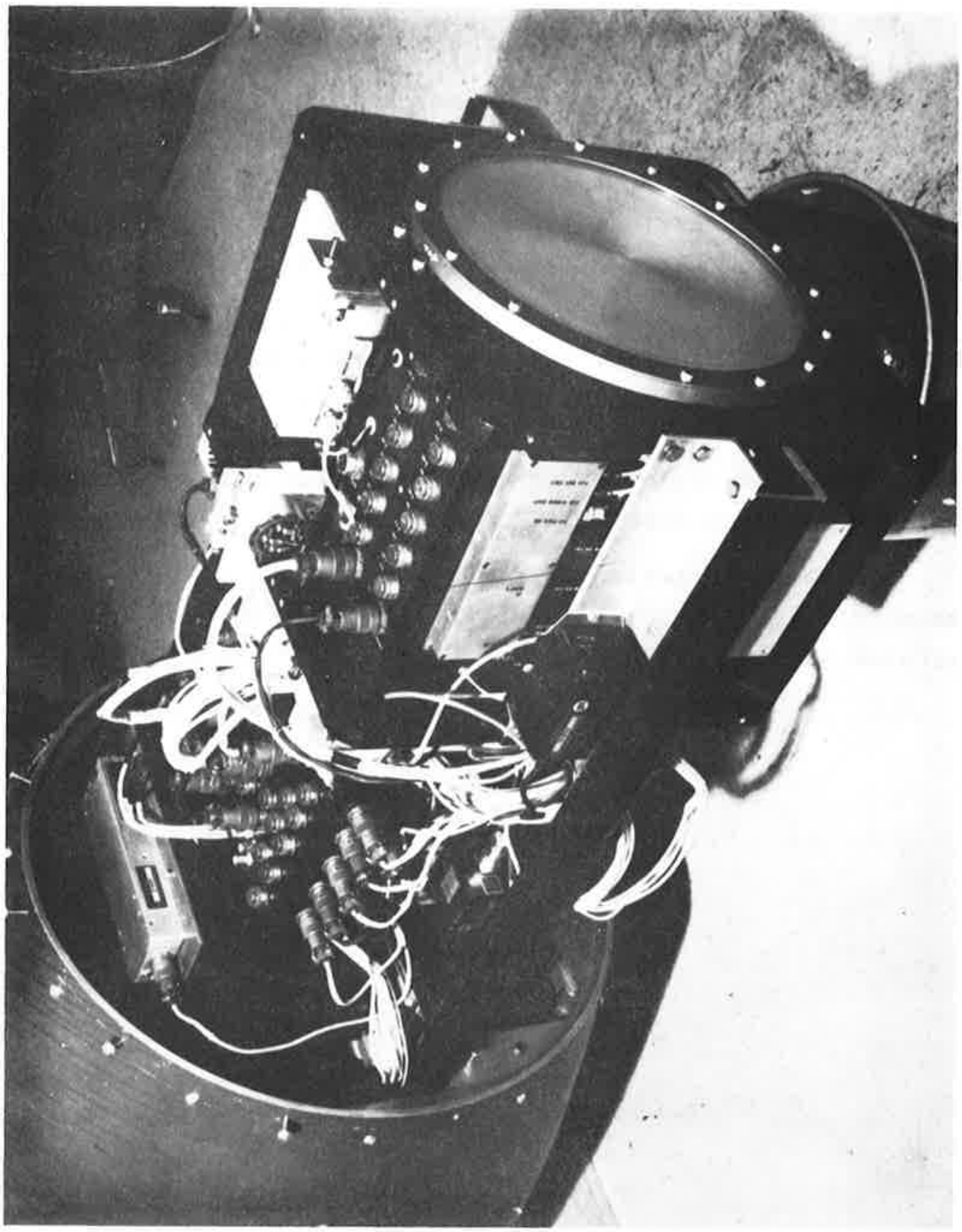


Figure 3-1. Radiometric Sensor System Package

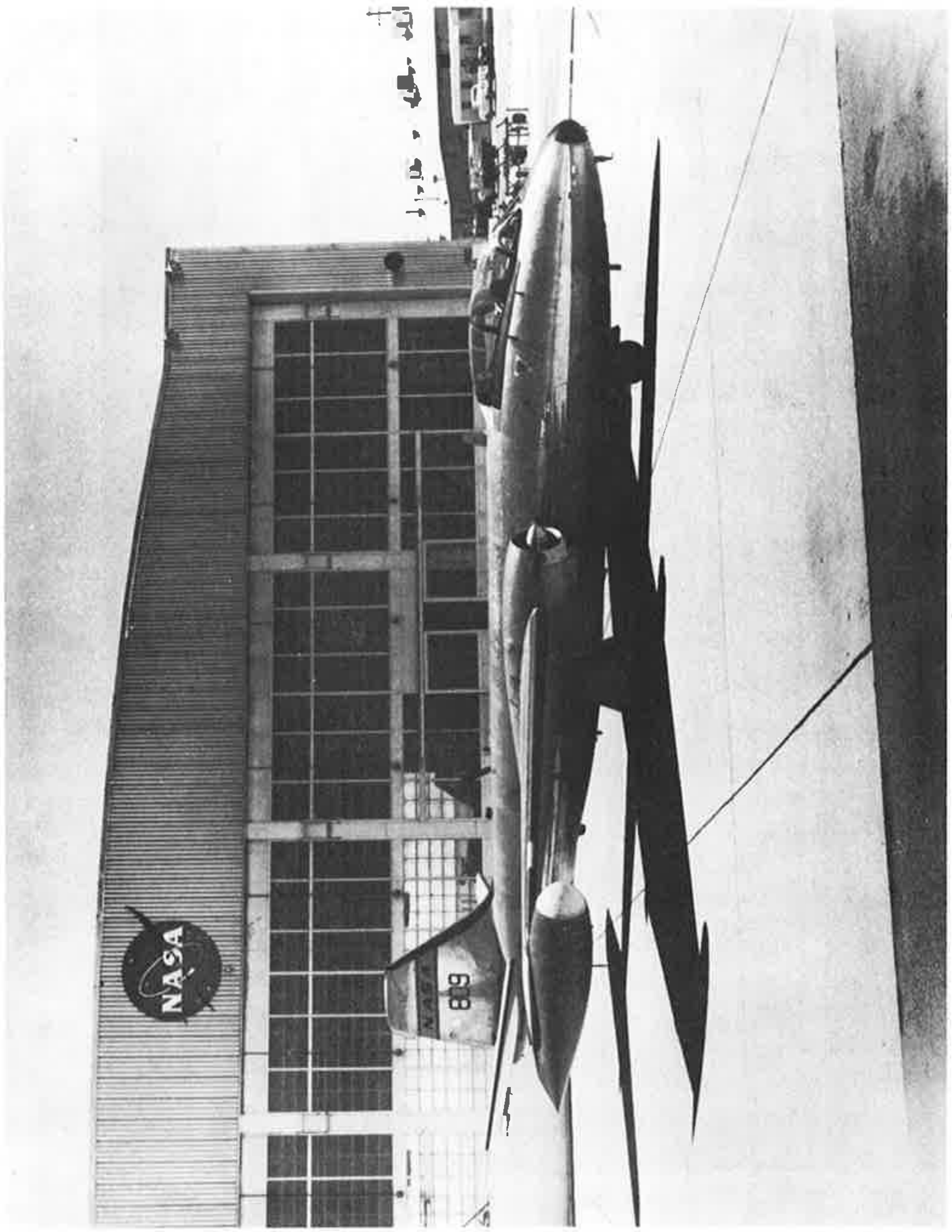


Figure 3-2 Angle View of TSC Pod on Wing Tip

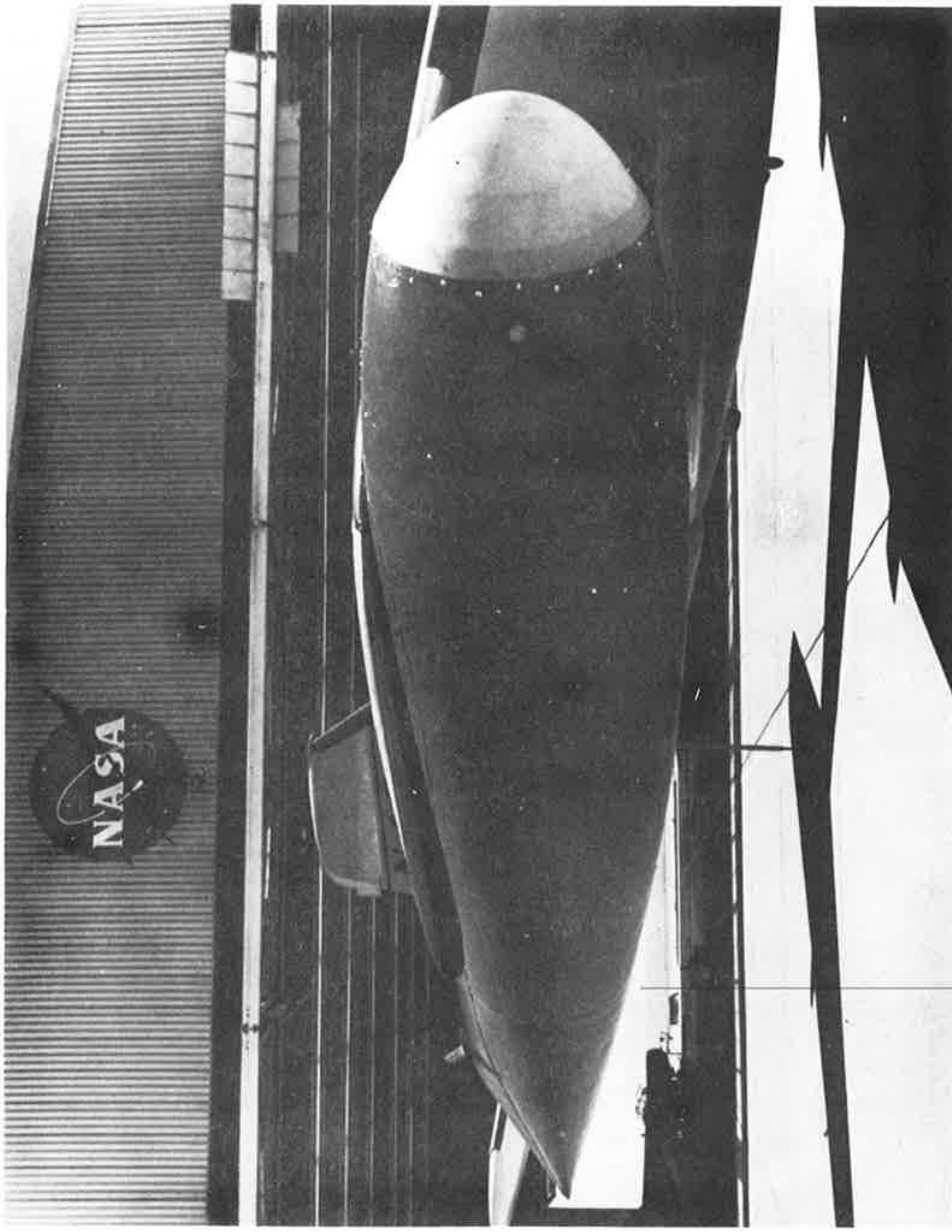


Figure 3-3 Instrumentation Pod Mounted on Wing Tip

TABLE 3-1 INSTRUMENTATION FOR FLIGHT DATA ACQUISITION

INSTRUMENTATION	FUNCTION	MANUFACTURER	DATA RANGE	SIGNAL RANGE
REMOTE SENSING 2 CHANNEL RADIOMETER	PROVIDES TWO ABSOLUTE TEMPERATURE SIGNALS AT TWO FREQUENCIES	DOT	-	± 2.5 VDC
AIR WEATHER SERVICE	PROVIDES TURBULENCE REPORTS			
ALTITUDE TRANSDUCER	FLIGHT ALTITUDE MONITOR	EDCLIFF	0-60,000 FEET	0-5 VDC
VERTICAL GYRO'S	MEASURES CHANGES IN AIRCRAFT PITCH AND ROLL ATTITUDE	LEAR	± 30°	± 2.5 VDC
ACCELEROMETERS	MEASURES "G"-FORCES IN THREE AXIS	EDCLIFF	± 10g	0-5 VDC
INCLINOMETERS	MEASURES CHANGES IN ATTITUDE OF THE CAT SENSOR	EDCLIFF	± 30°	0-5 VDC
TIME CODE GENERATOR	REAL TIME FOR RANGE CALCULATIONS	DATAMETRICS	-	0-5 VDC
VELOCITY SENSOR PROBE	INDICATES AIRSPEED AS AID FOR RANGE	DATAMETRICS	0-800 FT/SEC.	0-5 VDC
RADAR TRACKING	PLOTS AIRCRAFT LOCATION & HEADINGS	-	-	-
OUTSIDE THERMOCOUPLE	SENSES ATMOSPHERIC TEMP. AT THE AIRCRAFT	OHMIC	-80°F +120°F	0-5 VDC
INSIDE THERMOCOUPLE	SENSES POD INTERNAL TEMPERATURE	OHMIC	-30°F +150°F	0-5 VDC
TAPE RECORDER	RECORDS THE ABOVE DATA ON 14 CHANNELS	GENISCO	-	-
VOICE CHANNEL	RECORDS PILOT'S COMMENTS AND HIS REPORTS OF CAT ENCOUNTERS	-	-	-

4. FLIGHT TEST PROGRAM

4.1 FLIGHT OPERATIONS

The locating of the test site at the NASA/Flight Research Center, Edwards, California was based on the availability of a suitable aircraft that would accept the Radiometric CAT Sensor with minimum modifications to the aircraft. The aircraft, a NASA, B-57 Canberra provides the capability for attaining and operating at the 30,000 to 45,000 feet altitude required for the CAT missions. The operational area of all the CAT search missions were over mountainous and desert terrain within a 350 nautical mile radius of Edwards Air Force Base, California. Flight activities were coordinated with NASA/FRC on a non-interference basis and concurrent with other experiments. These factors and the seasonal aspects of turbulence activities in the high atmosphere limited the CAT operations to the time periods given in Table 4-1.

TABLE 4-1 CAT TEST OPERATIONAL PERIODS FOR FY 72

Dot Operational Dates @ FRC	Aircraft Availability	No. of Flights
8/03/71 to 8/23/71	8/09/71 to 8/20/71	1
11/29/71 to 12/07/71	12/03/71 to 12/07/71	1
12/13/71 to 12/30/71	12/14/71 to 12/30/71	4
1/03/72 to 1/07/72	1/03/72 to 1/05/72	1
1/23/72 to 2/19/72	2/01/72 to 2/19/72	3
4/05/72 to 4/25/72	4/17/72 to 4/24/72	5

4.2 SEASONAL ASPECTS

Statistics on the average number of reported turbulence occuring per month throughout the United States on a yearly basis were obtained from NASA/FRC. CAT encounters drop off to twenty percent probability or less than one a day during the warmer months. Taking into account a smaller area of operations, such as southwest USA, the probability of significant CAT encounters is reduced still more. Thus, flight operations for the warmer seasons were not justified and thus not conducted.

4.3 FLIGHT SCHEDULING

The initiation of the experimental program defined that the data could be accumulated in a four month period of time by utilizing optimum times determined from turbulence forecasts. The limitations however of meteorological forecast, aircraft, instrumentation and local weather conditions reduced the available amount of flight test operations that could be achieved to gather the required statistical data. The flight schedule shown in Figure 4-1 presents the actual end results for the reporting period on a single aircraft.

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. The fact that the aircraft was not dedicated to CAT testing decreased the actual number of hours of flight originally planned to provide the required statistical base for determining the constant false alarm rate associated with a radiometric detection system of this type.

4.4 FLIGHT PROCEDURES

Since a particular flight was contingent on the availability of an aircraft and pilot, a flexible flight plan was prepared. An example of the flight plan is shown in Appendix B based on a 24-hour forecast of possible CAT conditions. These forecasts were obtained

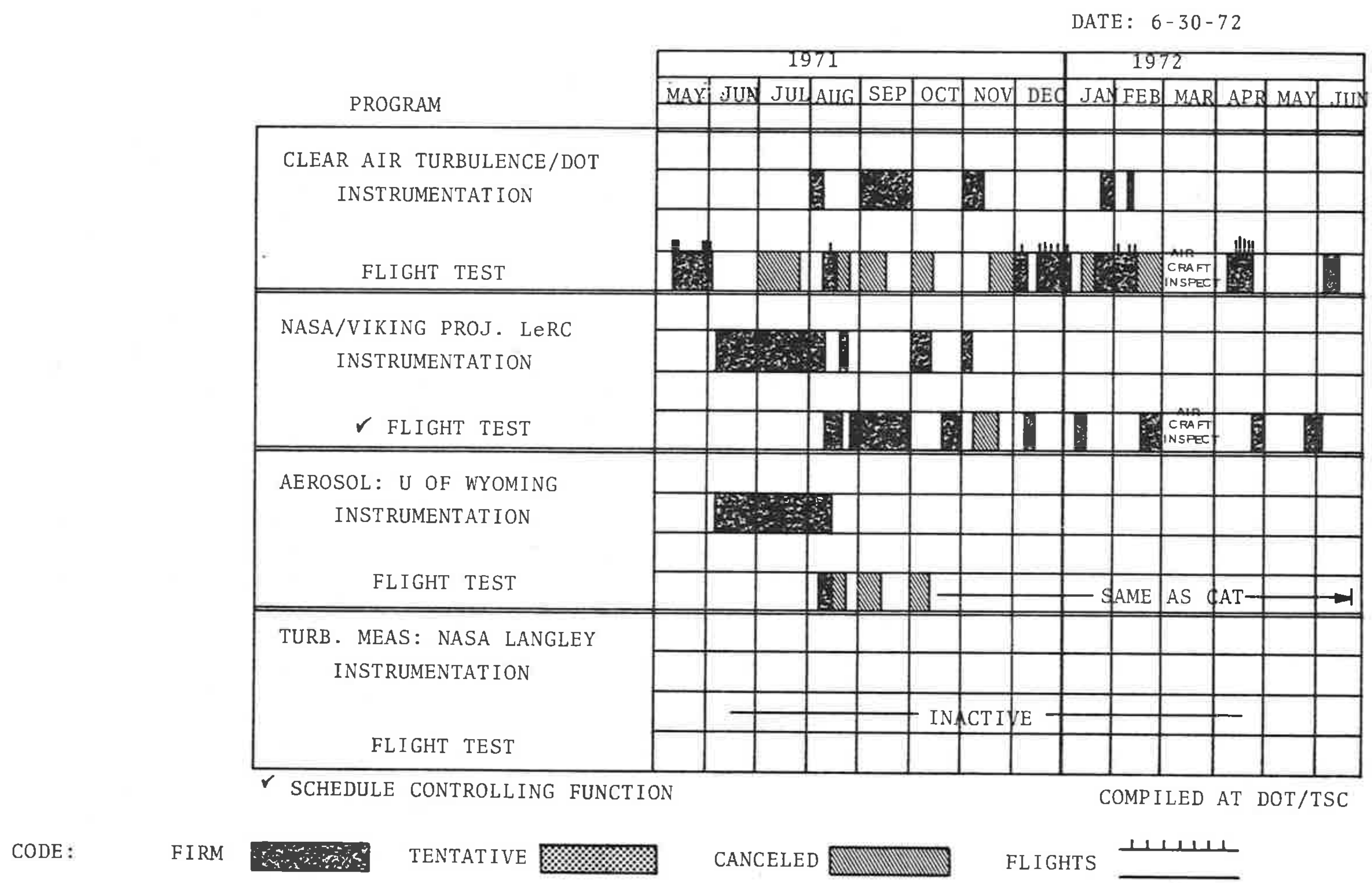


Figure 4-1 B-57 Test Aircraft Flight Schedule

from the Edwards Air Force Base Weather station and evaluated by NASA/FRC. On the flight day, the most recent morning weather observations were then re-evaluated for location, altitude and intensity of CAT conditions and a go-no-go decision for flight was made. When weather observation indicated CAT conditions at particular locations, weather stations in the vicinity were usually contacted by FRC for confirmation of turbulence reports in their areas. A pre-flight briefing was then conducted and any changes in the flight plan or CAT pattern procedure was presented to the test pilot (See Appendix C). The flights began between midmorning and noon time and lasted two to three hours. After the engines were started but before departure, the instrumentation was electrically checked to assure proper functioning of all the sensors.

The CAT searches normally began at the designated altitude and in the vicinity of the reported turbulence. When no turbulence was encountered, weather checks were made in flight by the pilot of other possible CAT reports. Otherwise, the remaining flight time was spent on concurrent experiments. If turbulence of significant intensity extended over a wide area, the pattern was repeated, time permitting. Immediately after a flight, the instrumentation was rechecked electrically for possible changes in the sensor signals. Thus, any malfunctions that occurred were corrected without delaying future flight schedules. This was followed by a pilot's debriefing on all aspects of the flight. Oscillograph records were made and processed for preliminary examination of the flight results and to assure that proper data was recorded.

4.5 METEOROLOGICAL CAT PREDICTIONS

One of the major factors for preflight planning of a CAT mission was the examination of weather forecasts and pilots' reports of the possible existence or occurrence of clear turbulence at high altitudes within the operating range of the test aircraft. Predictions of CAT had to rely mainly upon the forecast data available at the Edwards Air Force Base weather office and the interpretation of this data by NASA/FRC, USAF and DOT/TSC personnel.

Early in the program, turbulence predictions were dependent on numerical data of pressure fields, temperature fields and winds aloft charts that were 18 to 24 hours old by the time a test was conducted. Therefore, forecasting of various atmospheric parameters had to be well in advance to evaluate conditions for flight scheduling. The method was later refined by observing and evaluating atmospheric conditions 24 hours, 12 hours and 2 hours in advance of a scheduled flight. This weather data was obtained from the daily weather maps (pressure flow), winds aloft charts, temperature-altitude inversion layer plots, teletype station reports and pilot's reports. Predictions were then made and based on favorable indications of the following atmospheric parameters:

- upper level frontal zones activities;
- sharp changes in horizontal temperature gradient at a constant altitude;
- large horizontal wind shear and directional changes at a constant altitude;
- sharp changes in vertical temperature gradient;
- rapid changes in vertical wind speed and direction shifts;
- jet stream associated with troughs aloft and wind shift zones.

These observations were made for pressure levels of 500 mb to 150 mb and provided a means for selecting a flight altitude and flight track to the location with the greatest differential temperature, a characteristic of CAT.

This method of prediction is not optimal due to lack of precise definition of turbulent air along the horizontal flight, the large areas of operation covered by the forecast, and the time lag between the final evaluation and attaining flight test altitude. However, during this series of CAT search flights it appears that at least six CAT encounters were reported out of eight predictions of turbulence although not of the intensity anticipated. The pilot's debriefing report was usually the factor in confirming CAT encounter with respect to the prediction accuracy.

5. DATA ACQUISITION

5.1 OVERVIEW

The process of collecting flight test data resulting from the measurement of the meteorological parameters associated with CAT consisted of recording voltage signals on a fourteen channel tape recorder. Magnetic tape was used as the primary recording medium. In addition, the pilot's debriefing notes and flight track charts supplemented this tape data. The flight test parameters collected are given in Table 3-1 and test time including the pilots comments in Table 5-1.

A CAT search normally began at planned altitudes. However, the instrumentation and airborne recorder were operated continuously throughout the flight, that is, from the time the aircraft engines were started to the time of shut down. This provided an overall cross-section of the complete flight for post-flight data review and the data reduction process.

As the composite flight test log shows in Table 5-1, fifteen test flights were made starting with flight 7 for this test period totalling 31.5 flight hours. A total of 25 hours of flight data tape was recorded but it should be noted that this includes flights with no CAT encounters.

The flight sensor system was operated continously during fifteen test flights. Fourteen of these were within separate operational periods between December 1, 1971 and April 30, 1972 as shown in Table 4-1. The statistics of these missions break down as follows:

Number of Flights...................15

Total Flight Time...................31.5 hours

Other Experiments...................5 hours

CAT Search Time (Estimated).........15.0 hours

Total CAT Search Data Tape..........20 hours

TABLE 5-1 COMPOSITE TEST LOG

FLIGHT TEST NO.	DATE	PURPOSE	FLIGHT TIME IN HOURS	CAT SEARCH	TAPE TIME IN HOURS	ALTITUDE IN 000's OF FEET	RESULTS
FLIGHT 1 TO 4 ①	MAY'71	SHAKEDOWN FLIGHTS	4.5	②	3.0		EQUIPMENT CALIBRATION ADJUSTMENTS
FLIGHT 5,6	2 JUN'71	INITIAL CAT SEARCH	3.5	2.5 HRS	3.5	35 25	TWO LIGHT CAT ENCOUNTERS NO SIGNIFICANT DATA
FLIGHT 7 ①	13 AUG'71	COMBINED AEROSOL DOT/CAT SEARCH	1.5	1.2 HRS	1.5	-	NO CAT ENCOUNTERS
FLIGHT 8 ①	3 DEC'71	NASA CAMERA TEST CAT SEARCH	2.3	2.0 HRS	2.3	9 44	INADEQUATE LIGHT SCATTERED CAT-NO DATA
FLIGHT 9 ①	15 DEC'71	COMBINED AEROSOL DOT/CAT SEARCH	2.0	1.3 HRS	2.0	-	NO CAT ENCOUNTERS EXCESSIVE AEROSOL SPIRALS
FLIGHT 10 ①	17 DEC'71	COMBINED AEROSOL DOT/CAT SEARCH	1.9	0.5	1.5	-	NO CAT ENCOUNTERS EXCESSIVE AEROSOL SPIRALS
FLIGHT 11 ①	23 DEC'71	COMBINED AEROSOL DOT/CAT SEARCH	1.7	1.4	0—	-	NO CAT ENCOUNTERS DATA RECORDER NOT TURNED ON
FLIGHT 12 ①	30 DEC'71	COMBINED AEROSOL DOT/CAT SEARCH	1.5	1.0	0—	-	NO CAT ENCOUNTERS DATA RECORDER NOT TURNED ON
FLIGHT 13 ①	4 JAN'72	COMBINED AEROSOL DOT/CAT SEARCH	2.5	2.0	0.35	43	LIGHT CAT ENCOUNTERED RAN CAT PATTERN. DATA RECORDED ONLY DURING 20 MINUTE PATTERN AUXILLIARY SENSORS CONFIRMED CAT

TABLE 5-1 COMPOSITE TEST LOG (CONTINUED)

FLIGHT TEST NO.	DATE	PURPOSE	FLIGHT TIME IN HOURS	CAT SEARCH	TAPE TIME IN HOURS	ALTITUDE IN 000's OF FEET	RESULTS
FLIGHT 14	2 FEB'72	AIRCRAFT PITCH ATTITUDE CALIBRATION	2.3	③	2.3	10 30	CONFIRMED AIRCRAFT FLYING NOSE HIGH. LIGHT AND HEAVY TO SEVERE ENCOUNTERS
FLIGHT 15	14 FEB'72	CAT SEARCH	1.5	1.2	1.5	40	PILOT REPORTED LIGHT TO MODERATE TURB. ENCOUNTER. DATA CONFIRMED RADAR PLOT USED
FLIGHT 16 ①	15 FEB'72	CAT SEARCH	3.0	1.5 HRS	3.0	29 33 31	A HEAVY AND SEVERE CAT ENCOUNTERED NOISE TUBE FAILURE - ATMOS. SENSOR DATA CONFIRMS CATS
FLIGHT 17	18 APR'72	CAT SEARCH	3.0	2.5 HRS	3.0	5 33 35	LIGHT AND MODERATE TURB ENCOUNTER
FLIGHT 18	19 APR'72	CAT SEARCH	2.8	1.3 HRS	2.8	31	LIGHT AND LESS THAN LIGHT TURB
FLIGHT 19	20 APR'72	CAT SEARCH	3.0	2.4 HRS	3.0	31 41	LIGHT AND MODERATE ENCOUNTER
FLIGHT 20 ①	21 APR'72	CAT SEARCH	0.8	0.2 HRS	0.8	40	NO TURB ENCOUNTERS
FLIGHT 21 ①	24 APR'72	CAT SEARCH	1.3	②	1.0	22	VERY LIGHT TURB ENCOUNTERS

① FLIGHT TIME SHARED WITH OTHER EXPERIMENTS

② CONCURRENT EXPERIMENT MISSION - NO CAT SEARCH - DOT EXPERIMENT "ON"

③ NO CAT SEARCH BUT CAT ENCOUNTER - NO PATTERNS

The number of individual turbulence encounters obtained from the pilot's airborne reports on the magnetic tape voice channel and debriefings are summarized in Table 5-2.

TABLE 5-2 NUMBER OF INDIVIDUAL TURBULENCE ENCOUNTERS

Number of Flights	Intensity Class	Number of Encounters
6		0
10	Very light to Light	23
5	±Moderate	6
2	±Severe	2

A detailed evaluation of each flight performed is listed by flight number and appears in Appendix D. These flights start with Flight 7. The previous six flights were discussed in an earlier report.[5]

5.2 DATA PROCESSING AND REDUCTION

Processing of the magnetic tape to retrieve flight data from the airborne recorder is accomplished through a playback recorder with the same electronic characteristics as the airborne recorder. Taped data is first converted back to voltage signals and displayed on voltmeters or oscillograms at the test site and used for a post-flight cursory review of the results. The data obtained immediately after each flight is also used for future flight planning and repair or calibration of the sensors when the data indicates the need exists. At the same time, the temperature, acceleration, and CAT sensor parameters (including the pilot's taped reports) are reviewed to verify atmospheric conditions which are forecasted prior to flight. When time permits, closer observations of the data are made between test flights. Otherwise, all the test data in the form of magnetic tape, meteorological charts, flight plans, flight course maps, pilot's debriefing reports and any oscillographs are returned to DOT/TSC for a thorough analysis.

For the final data analysis, the flight test magnetic tape is reprocessed on oscillographs to include real time and notations of comments by the test pilot on turbulence encounter. Events of turbulence are then selected based on vertical acceleration response and unusual sudden temperature changes in the oscillosgraph trace. These parameters are compared with the aircraft attitude roll and pitch traces (gyro response) as well as the pressure transducer trace for constant altitude during a turbulence penetration. Whenever the attitude data indicates excessive aircraft motion in a particular sample, the sample is normally eliminated as unusable data. After a sample event is selected beginning and end times are established. The data conversion back to actual flight parameter values are then completed. With the data conversion back to real values, such as, temperature, etc., it is possible to evaluate the response of the radiometric CAT sensor to a turbulence event before and during penetration.

The intensity of a turbulence encounter is another important consideration for both selecting a data sample and evaluating the CAT sensor. Turbulence of low intensity produced little or no temperature differences. Consequently, the radiometer recorded signals too low for an accurate data analysis of the turbulence intensity.

As an aid for the data reduction phase, CAT encounters are classified by intensity. Classification of intensities used herein were based on the pilot's description during an encounter, by the acceleration peak "g" levels recorded in the test data and the "rms" values taken from "Federal Plan for CAT", Dept. of Commerce, 1969 as shown in Table 5-3.

In summary, the CAT sensor equipment was in an operational mode through out the fifteen test flights evaluated above. During two of the flights, the data tape recorder was in the non-recording mode producing no data for lack of turbulence activity.

On one flight, failure of the sky temperature balancing component in the radiometer eliminated use of the channels A and B data but good atmospheric data was obtained from the ancillary sensors. As previously stated no turbulence conditions existed in six

TABLE 5-3 CLASSIFICATION OF CAT INTENSITY[6]

CAT Description	Peak "g" Increments	RMS "g" Increments
Light	±0.10 to ±0.30	
Moderate	±0.30 to ±0.60	0.2-0.3
Severe	±0.60 to ±1.20	0.3-0.6
Extreme	±1.20<	0.6<

of the flights. The CAT encounters ranging from very low to severe intensities during the remaining nine flights were analyzed. The light CAT encounters did not produce significant data for evaluation because of their short durations and the difficulty created by the flight profile of the B-57. Flights 15 and 17 data provided some good samples of temperature anomalies and indicated the radiometric CAT sensor as receiving these anomalies in a normal manner. Flight 16, of course, was considered the ideal flight for detection but unfortunately the one and only failure occurred during this mission. Full details and flight data from all the flights can be found in Appendices E, F, and G.

Thorough evaluation of the weather forecast data for the higher altitudes prior to flight produced about seventy-five percent of the CAT encounters predicted although not always of the intensity expected. It does however point to the importance of this phase of the flight planning for a detection type mission.

6. CONCLUSIONS

The following conclusions are based upon a review of the analyzed data obtained and observations during flight test operations at NASA/FRC, Edwards, California.

a. Refinement of the flight operational procedures, from experience gained through the first fifty percent of the flight program and increased coordination with NASA/FRC, has advanced the preflight planning and equipment handling to a point where a CAT flight could be conducted in a minimum time with minimum manpower effort.

b. Equipment repair can be accomplished within twenty-four hours if spare parts are available at the test site. A catastrophic failure of the Radiometric CAT Sensor however, would cause an extended delay. Only a one day slippage was incurred for a single flight due to a component failure for the test period just completed.

c. The capability of the radiometric sensor to sense temperature anomalies as well as lapse rate was confirmed. The evidence is in data presented in this report. However, the small number of significant CAT encounters was inadequate to determine the false alarm and missed target rate.

d. The operating range of the aircraft was a limiting factor for CAT search missions and confined the test flights to the southwest corner of the United States. This does not imply that other locations of operation are necessary since the southwestern United States is considered a good turbulence area on a seasonal basis. In this respect, the data herein indicates the best seasonal period for conducting CAT flights in the 1st quarter of the calendar year. December and April also have possibilities but to a lesser degree. Turbulence activities taper off rapidly for the remaining months.

e. Weather forecast studies proved to be increasingly important for CAT predictions and were somewhat fruitful for the present test flight phase. This area is lacking however, in the quantity of weather and turbulence information that is available. Additional sources would be helpful for the turbulence predictions.

f. It was concluded from this report that turbulence exposures were markedly more severe over the Arizona-Colorado area and the CAT encounters were more intense at the 30,000 to 40,000 foot altitude levels.

g. It is further concluded that minute changes in aircraft motion had a much greater effect on the CAT sensor motion at the wing tip.

7. RECOMMENDATIONS

7.1 SENSOR DESIGN IMPROVEMENTS

a. A significant operational capability in the radiometric sensor may be incorporated without undue complexity. This can be accomplished in the following manner. An additional range granularity is possible by incorporating two additional radiometric channels into the presently terminated parts of the ferrite switches. The two channels would have frequencies of 54 GHz and 56 GHz and would not require any increase in the R.F. (Radio Frequency) waveguide. By using four radiometric channels the range resolution and accuracy of the sensor would be greatly improved. Although the turbulence would not be detected any earlier, the range to the CAT could be determined much earlier and with greater precision than is now possible with the present two channels. Secondly, if the sensitivity of the mixers were improved by utilizing current technological improvements in matched receiver crystals then an increase in the range of up to one hundred miles could be achieved. This technology means improvement in the overall system noise figure of the radiometric sensor and also would not be difficult to achieve.

b. The mechanical configuration and reliability of the instrument may be improved by simplifying the R.F. waveguide section of the sensor. At present the receiver is solid state including two Gunn oscillators that function as local oscillator injection. The R.F. section also includes two Argon gas discharge noise tubes. These tubes are constructed of 1/16 inch glass tubing, and are very fragile and have a guaranteed operating life of 100 hours maximum. The tubes provide "calibration" and "balancing" of the R.F. input of the receivers. (It was this tube that was responsible for the only serious failure during flight tests.) This tube can be completely eliminated and the present heated oven replaced by a theromoelectrically cooled oven. This cooled oven could operate at the outside ambient temperature at all altitudes, thus negating the requirement for noise tubes and assorted power supplies.

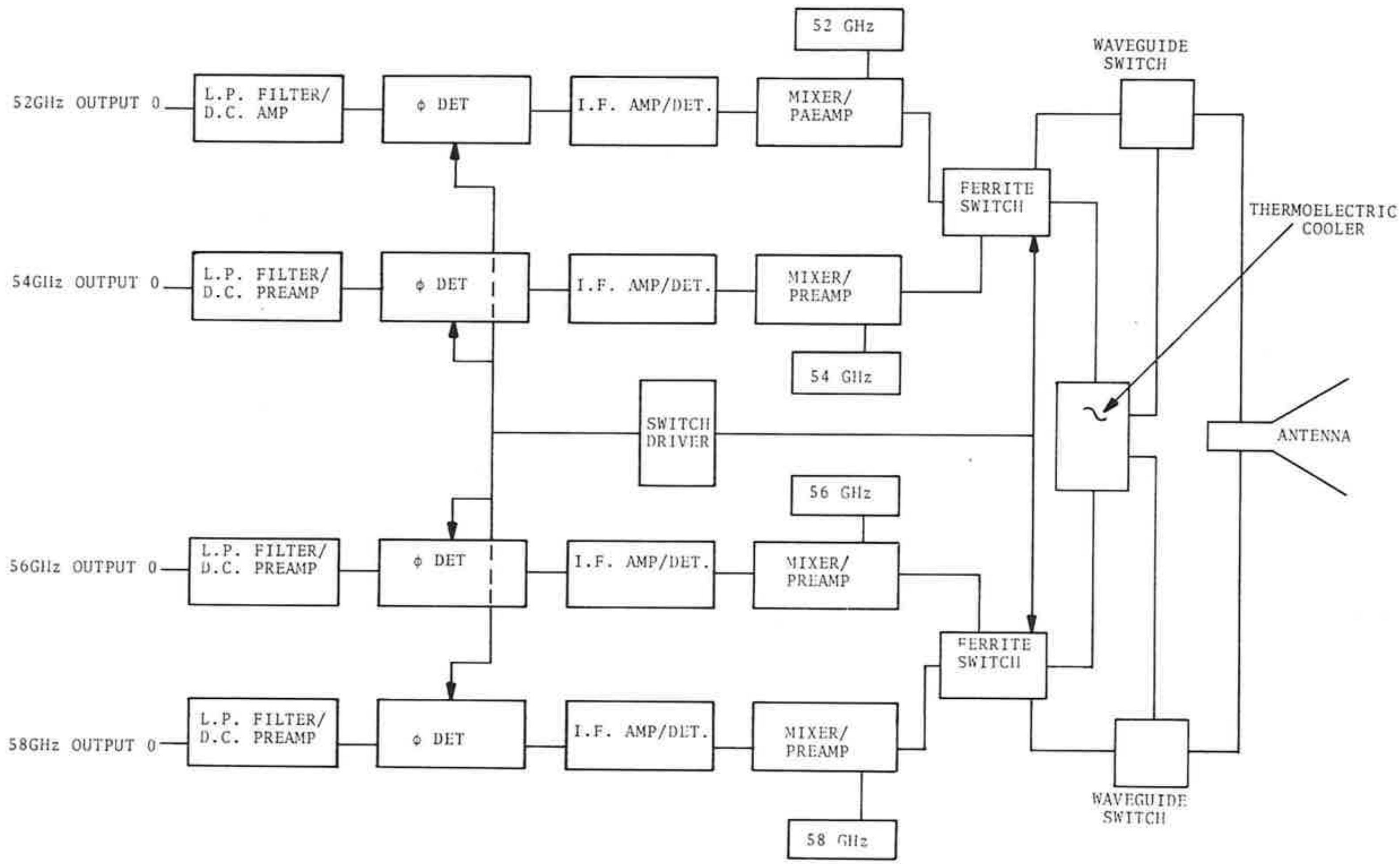
Figure 7-1 presents a block diagram of such a solid state four channel radiometric receiver.

7.2 OTHER IMPROVEMENTS OF LESS SIGNIFICANCE

Accelerometer: Reducing the range down to ±3g's sensitivity will provide a higher readable voltage signal thereby increasing the accuracy of real value during data reduction.

Based on the results of past test flights, it is recommended that the flight test program be continued to obtain additional CAT detection data.

It is apparent from the data presented that the flight system has the capability to identify and measure atmospheric temperature anomalies and aircraft attitudes. What remains is the need of a sufficient number of high intensity encounters or runs on a CAT in order to evaluate the constant false alarm rate of the sensor. It is possible to accomplish this task with a continous program during the season when the turbulence probability is the highest. Such a program must be accomplished in conjunction with a better method of acquiring weather information so as to more accurately predict CAT and its general location. Although this is a task in itself, it is a necessity in order to eliminate the accumulation of unusable data.



7-1 Four Channel Solid State Radiometric Sensor

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3. Collinson, J.A., J.S. Cook, and M. Subramanian, Lasar detection of clear air turbulence, U.S. Patent No. 3,540,829, U.S. Patent Office, Washington, D.C., (1972).

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5. Wagner, G.W., G.G. Haroules, and W.E. Brown, Clear air turbulence radiometric detection program, Ann. Rept. No. DOT-TSC-FAA-71-19, DOT/TSC, Cambridge, MA, (1971).

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APPENDIX A

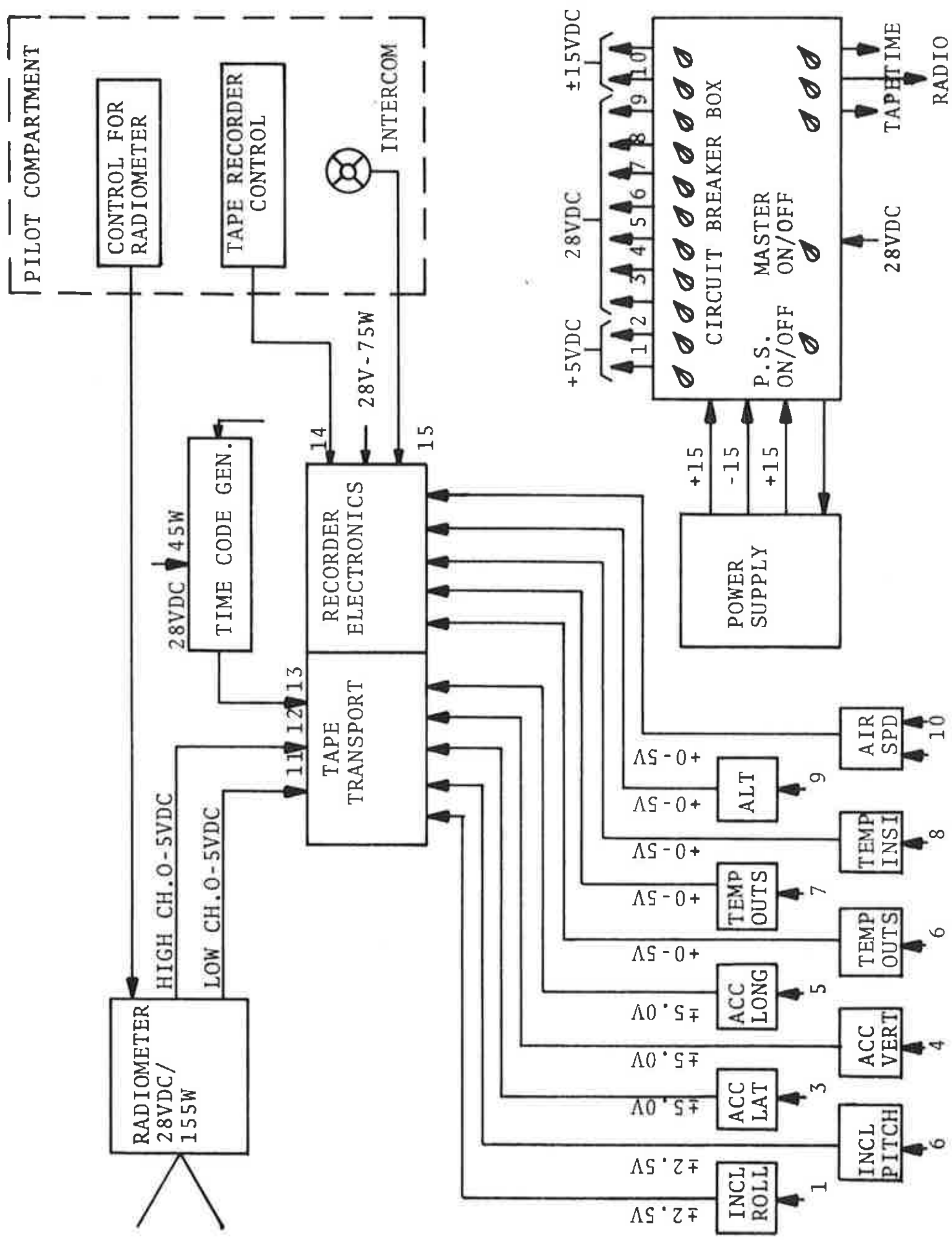


Figure A-1 CAT Sensor System Instrumentation Schematic

APPENDIX B

STANDARD CAT FLIGHT PLAN

TEST SITE: NASA/Flight Research Center

Flight No. ________ Aircraft B-57 #809 Date of Flight ______

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 or 40,000 ± 5,000 feet and report at each 5,000 ft; time, heading, airspeed, rate of climb and outside temp.

(2) Stabilize altitude feet and maintain straight level flight as condition permits. Airspeed may vary to hold level flight condition.

(3) Proceed predicted turbulence 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 proceed with CAT pattern after passing thru turbulence and report all compass heading time, and any altitude changes on intercom.

(5) If CAT is not encountered at 30,000 or 40,000 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 time permits.

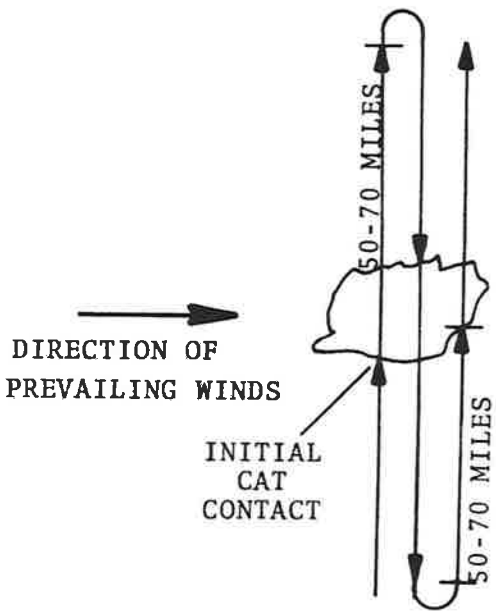
(6) Returning to base - report time and altitude at end of search on intercom.

(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
	OUTBOUND, 50-70 MILES
	180° TURN
	INBOUND, 50-70 MILES
	OUTBOUND, 50-70 MILES
	180° TURN
	INBOUND, 50-70 MILES
	OUTBOUND, 10 MILES
	END OF PATTERN

NOTE:

1. CAT MISSED-RELOCATE & REPEAT PATTERN
2. REPORT PASSING THROUGH CAT-INTENSITY & G-FORCE

Figure C-1 Flight Pattern After CAT Encounter (Revised)

APPENDIX D

SENSOR DESCRIPTION

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 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 attidude 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 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.

APPENDIX E

CAT ENCOUNTER TABLE

TABLE E-1 CAT ENCOUNTERS BY INTENSITY

FLIGHT NO.	ALTITUDES x 1000 FT.										COMMENTS
	5-6	9-10	20-22	27-29	30-31	33	35	37	40-41	43-44	
7 (AUG)											RUN ON CLOUD - NO RESPONSE AS EXPECTED
8 (DEC)		L								L	CAT SEARCH - LOCAL
9 (DEC)											NO CAT
10 (DEC)											NO CAT
11 (DEC)											NO CAT
12 (DEC)											NO CAT
13 (JAN)										L	CAT SEARCH - CROSS COUNTRY
14 (FEB)		S			L						INCIDENTAL FLIGHT
15 (FEB)									L L TO M		CAT SEARCH RAN PATTERN
16 (FEB)				2 LC	L,M SC	MC,L LC, HM					CAT SEARCH COLO. RIVER & NEEDLES PRESCOTT INBOUND PHOENIX OUTBOUND PHOENIX

VL = VERY LIGHT LC = LIGHT CONTINUOUS M = MODERATE HM = HEAVY TO MODERATE
L = LIGHT Li = LIGHT CHOPS MC = MODERATE CONTINUOUS S = SEVERE

TABLE E-1 CAT ENCOUNTERS BY INTENSITY (CONTINUED)

FLIGHT NO.	ALTITUDES x 1000 FT.										COMMENTS
	5-6	9-10	20-22	27-29	30-31	33	35	37	40-41	43-44	
17 (APR)	M			$L_{MT-WAVE}$		L L - M	2VL,1L				CLIMB OUT TO SEARCH AREA SOUTHWEST OF PEACH SPRINGS PEACH SPRINGS " " TO PRESCOTT AREA
18 (APR)					L 3VL 1Li 1VLi						CAT SEARCH PEACH SPRINGS PEACH SPRINGS HECTOR
19 (APR)			VL					L	Li Mi LC		CAT SEARCH WINSLOW & TUBA CITY BRYCE CANYON BRYCE CANYON
20 (APR)											NO CAT - CAT SEARCH
21 (APR)	L		VL								MOUNTAIN AREA - IN CLIMB

VL = VERY LIGHT LC = LIGHT CONTINUOUS M = MODERATE HM = HEAVY TO MODERATE
L = LIGHT Li = LIGHT CHOPS MC = MODERATE CONTINUOUS S = SEVERE

APPENDIX F

LOG OF TEST FLIGHTS

Flight 7 (8-13-71)

This flight was planned as a CAT search mission. Meteorological data at pre-flight indicated no clear air turbulence in the immediate area. No CAT encounters were reported as predicted. The pre-planned back-up mission consisting of pattern runs on cloud formations were performed to verify that the Radiometric CAT sensor does not sense clouds. Analysis of the flight data confirmed this was the case. A good set of data was obtained from this flight and showed that all the sensors were functioning as expected. The constant change in slope of the CAT sensor and temperature with changes in altitude confirmed sensing of the lapse rate. The acceleration trace on the oscillograph had no variations except during pitch maneuvers of the aircraft.

Flight 8 (12-3-71)

There were two light turbulences reported in this flight. One at 9,000 feet and the other at 44,000 feet. The data analysis confirmed both CAT encounters by a 1 degree change in ambient temperature and 0.1g acceleration change upon penetration. The gyro pitch and roll, altitude and velocity traces were considered constant during these runs.

These encounters occurred immediately after the aircraft turned and therefore, no change was observed in the CAT sensor data that could be analyzed. The possibility of CAT was predicted from meteorological forecast over the mountainous area of operation for this mission.

Flights 9, 10, 11, 12 (12-15; 12-17; 12-23; 12-30-71)

No turbulence was predicted or encountered on these CAT search flights. The test data indicated no unusual variations in the recorded parameters for flights 9 and 10. The oscillograms were relatively constant except for slope changes with lapse rate. The airborne tape recorded was not turned on for flights 11 and 12 due to absence of turbulence. Therefore, no data was available.

These test flights were conducted over the Sierra Nevada mountain range where an occasional intermittent mountain wave of less than ten seconds persisted.

Flight 13 (1-4-72)

This flight consisted of a six leg cross-country trip ranging to a point 200 miles south of Salt Lake City, Utah and down through Prescott, Arizona (see attached track map, Figure F-1). The flight plan was based on the meteorological prediction of a possible low intensity turbulence in Tuba City, Arizona area.

A light turbulence was encountered at 43,000 feet, 90 miles south of Tuba City. Twenty minutes of data tape was recorded within the turbulence during a single DOT/CAT pattern run. It was concluded that the turbulence was too light for detection. The data analyzed showed constant temperature and altitude during this run consequently, the two radiometer traces were also constant. The peak accelerations indicated less than ±0.2g's confirming a light turbulence encounter. A 5°C temperature increase was reported after penetration but no data was recorded before penetration to verify this changed. In the latter part of this flight the radiometric sensor 52 GHz channel sensed the cold sky temperature and was attributed to a high pitch angle due to the high altitude and lower speed of the aircraft.

Flight 14 (2-2-72)

The flight was scheduled primarily to investigate the pitch attitude of the aircraft at various air speeds, altitudes and fuel loads. This task became necessary when data from recent flights began to show that the radiometer 52 GHz channel (far sensing) was sensing exceedingly cold lapse rate temperatures at high altitudes. It should be noted at this point, that the radiometer antenna is boresighted to see the same target as the longitudinal axis of the aircraft.

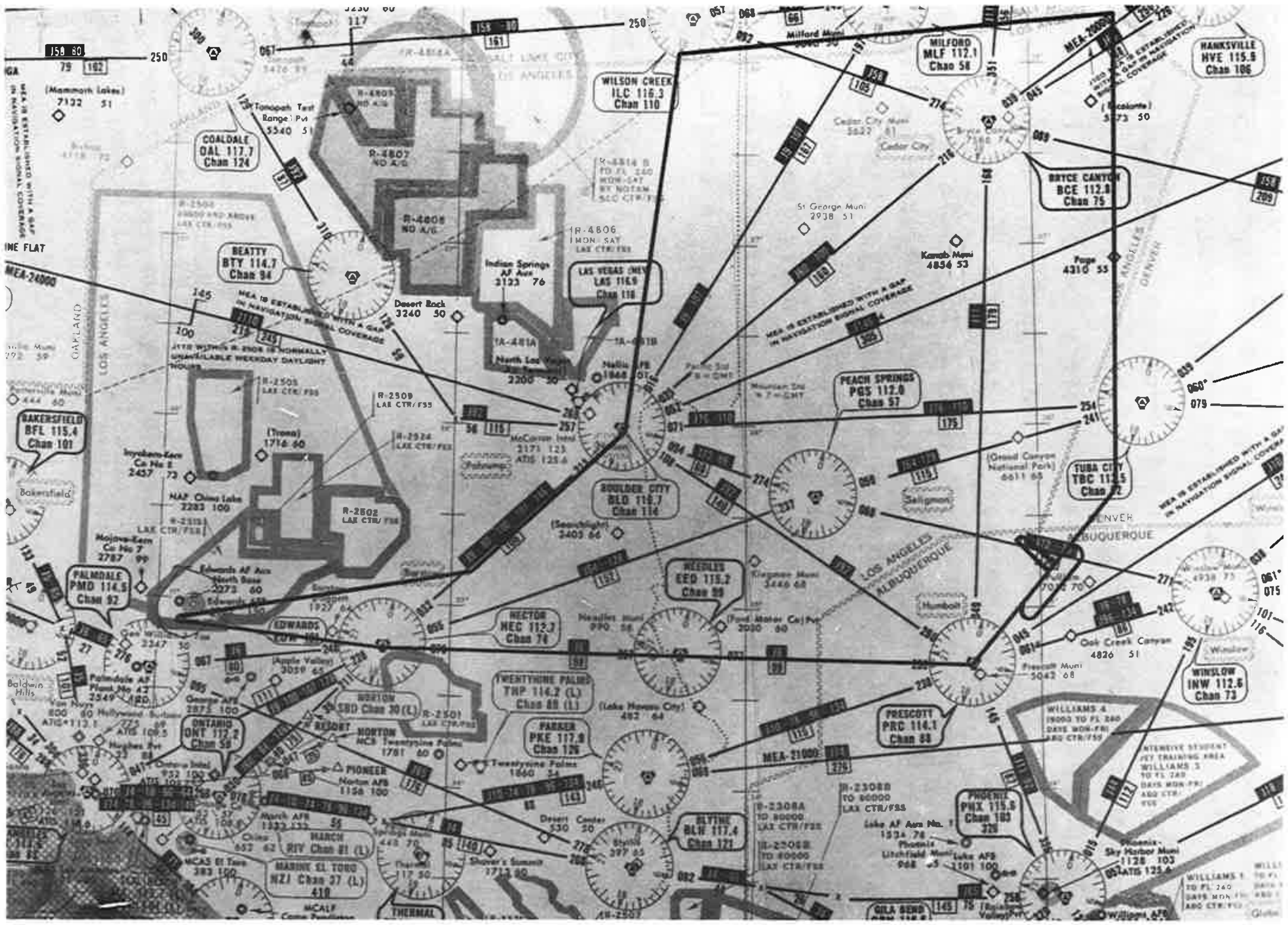


Figure F-1. Flight Number 13; Track Map

As a result of this flight and through the efforts of FRC, nine sets of speed-altitude curves were obtained. A study of these data curves by Einor Enevoldson (NASA Test Pilot) further resulted in an operating window of 220 ± 10 knots for a ±0.25 degree pitch attitude of the aircraft at all altitudes above 10,000 feet.

Since this was not a planned CAT search mission weather forecast studies were not made for this flight however, two CAT encounters were reported. The locations are given on the flight chart, Figure F-2. The light turbulence had no significant data. The results of a data analysis for the data analysis for the moderate-to-severe encounter is presented in Table F-1*. With reference to the data table the vertical acceleration of 1g indicates a high intensity activity of 10 to 20 seconds duration. The CAT sensor apparently sensed the temperature differential slightly earlier than the thermocouple on the aircraft which is normally the case. Unfortunately, the CAT penetration occurred immediately after a change in direction eliminating the possibility of a ranging calculation.

Weather forecast studies indicated only minor temperature disturbances over the Sierra Nevada Mountains at high altitude. Based on this predication, the flight was planned for an altitude of 40,000 feet over Mt. Whitney, California.

Three temperature anomalies were reported by the pilot during a standard CAT pattern run. A flight chart, temperature anomaly plots and tabulated data values are presented in Figures F-3 and F-4 and in Table F-2, respectively.

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*The following is a list of the abbreviations used in the Tables in Appendix F: Time Code Gen = Time Code Generator, Peak Accel Vert G's = Peak Acceleration vertical in G's, Temp Amb °C = Temperature Ambient in Degrees Centigrade, Deg = Degrees, Radm = Radiometer, Ch = Channel, Vel = Velocity, Alt = Altitude, Accel. Lat G's = Accelerometer Lateral in G's, Inclin = Inclinometer, Enctr = Encounter

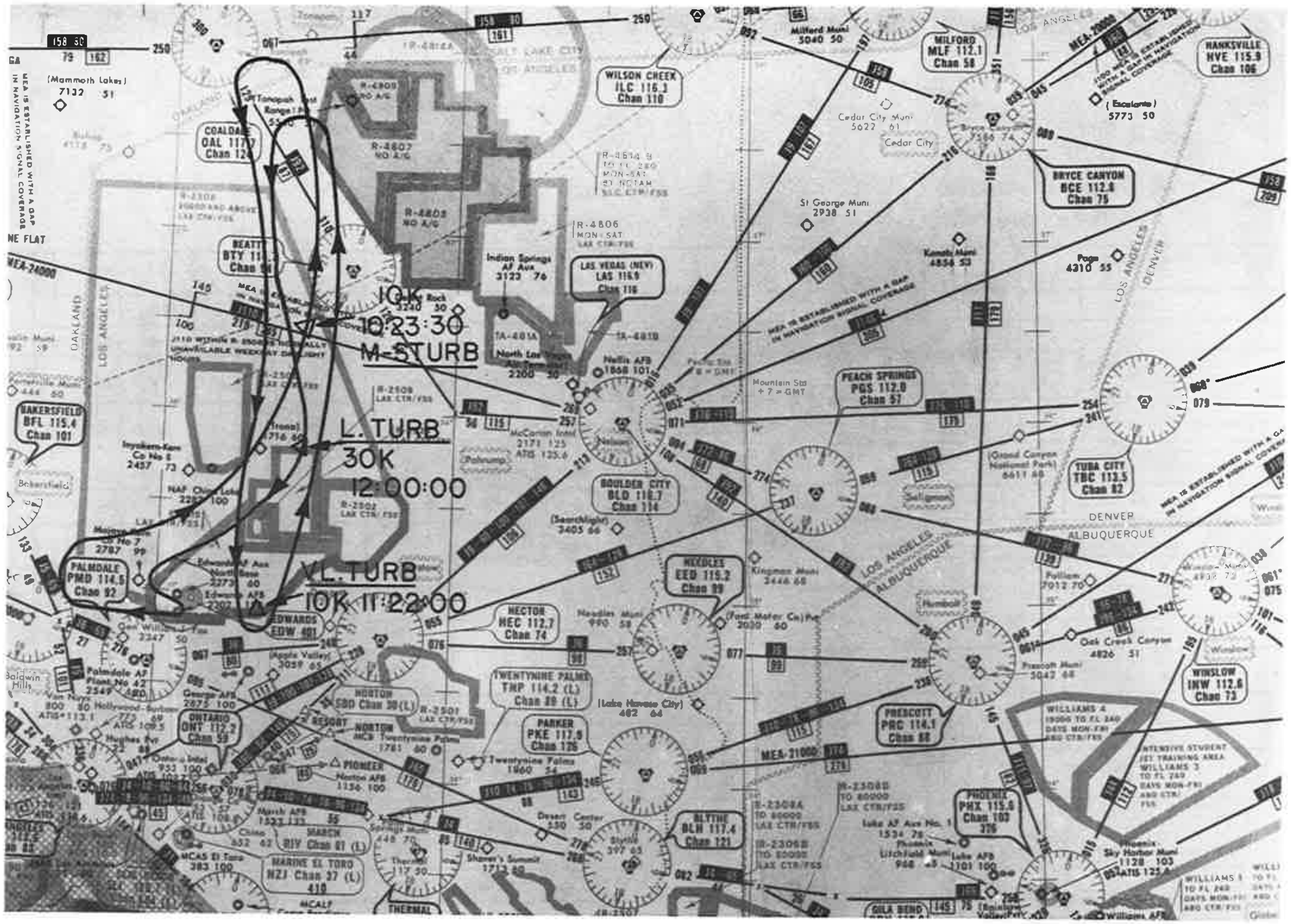

Figure F-2. Pitch Angle Calibration Flight; Flight 14, February 2, 1972
Δ = CAT Encounter

TABLE F-1. TEST DATA ON FLIGHT 14

CHANNEL NO.		11	4	13	10	9	7	8	5	3	14			
TAPE FOOT-AGE	TIME CODE GEN.	ACCEL VERT G'S	TEMP AMB. °C	GYRO PITCH AIRCRAFT DEG	RADM INCLIN PITCH DEG	RADM CH"A" 52GHZ	RADM CH"B" 58GHZ	VEL KNOTS	ALT FEET	ACCEL LAT G'S	INCLIN ROLL DEG	AIRCRAFT HEADING COMPASS	CAT ENCTR	REMARKS
		PEAKS	ΔT			ΔT	ΔT		X1000					Cat Run
	10:10:00	0	-2	0		-	-	200	10					
	10:13:00	0	-2	0		-	-	200	10					
	10:14:00	± .3	-2	-		0	0	250	10					g-Force Due to Start of a Right Turn
	10:15:00	± .3	-2	-		-	-	250	10					Completed Turn
	10:17:00	0	0°	0		0	0	250	10					Level Flight
	10:20:00	0	+1°	0		-	-	250	10					
	10:22:30	0	+1°	-		-	2°w	300	10					Just Before Left Turb w= Warmer
	10:23:00	± .2	+1°	-		-	1°w	300	10					In a Left Turn
	10:23:20	±1.0	+1.5°	-		1°w	2.5w	300	10				M-S	At Turn Completion Moderate Severe Turbulence
	10:23:40	±0.5	+3°	0		1°w	2.5w	300	10				M	Still in Turbulence but Decaying
	10:24:00	0	+3°	0		1°w	4°w	300	10				VL	In very Light Turbu-lence
	10:24:30	0	+4°	0		0	4°w	300	10				-	Turb End
	10:25:00	0	0	0		0	0	350	10					Climbing
	12:04:00	± .1							30				L	Insignificant Data

FLT. PLAN: PITCH ANGLE CALIBRATION FLIGHT DATE: 2 FEB 1972

DOT/TSC-FLT #14 TEST DATA ON FLIGHT 14

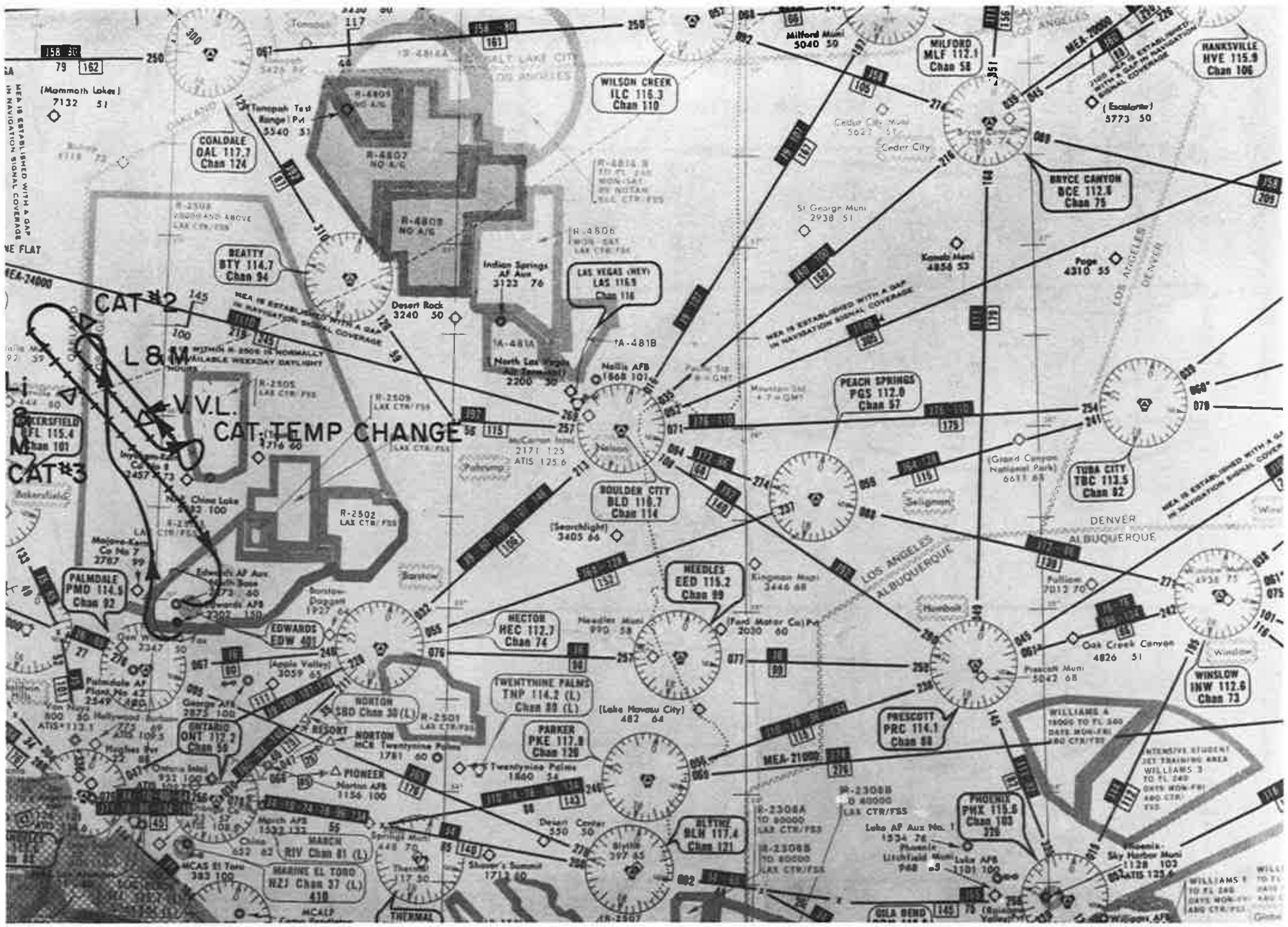

Figure F-3. CAT Search Track Chart; Flight 15; February 14, 1972
Δ = CAT Encounter

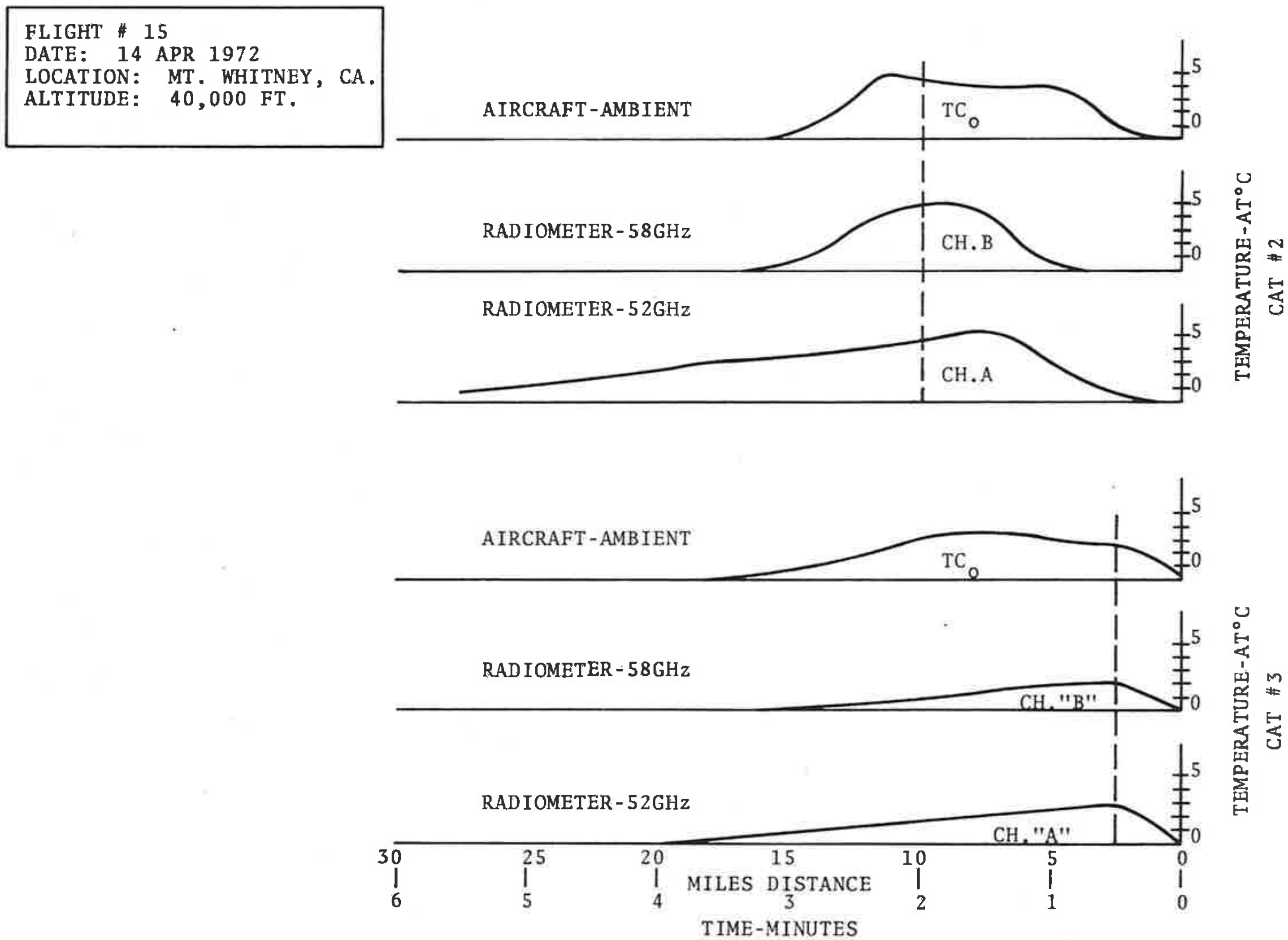

Figure F-4. CAT Encounter Sample; Flight 15; February 14, 1972

TABLE F-2. TEST DATA ON FLIGHT 15

CHANNEL NO.		11	4	13	10	9	7	8	5	3	14			
DATA SAM-PLE	TIME CODE GEN.	ACCEL VERT G's	TEMP AMB. °C	GYRO PITCH AIRCRAFT DEG	RADM INCLIN PITCH DEG	RADM CH"A" 52GHZ	RADM CH"B" 58GHZ	VEL KNOTS	ALT FEET	ACCEL LAT G'S	INCLIN ROLL DEG	AIRCRAFT HEADING COMPASS	CAT ENCTR	REMARKS
	H:M:S	PEAKS	ACTUAL			ΔT	ΔT		X1000			DEG	CLASS	
1	14:25:00		-39	↑	↑			220	35			338		Started Course Reversal - CAT Weak
	14:28:00		-41	↑	↑		+2°	220	37			150		On 1st Pattern Leg Tempera-ture Decrease with Altitude
	14:30:00		-44	↑	↑		+3°	210	39			150	VL	Still in Climb Insignificant CAT
	14:30:30	±.08	-44	2.0↑	0.3↑		+5°	210	40			150	VL	Some CAT Chops
	14:31:00	±.1	-39	"	"		0	210	40			150	L-M	Sudden Temperature Change Still Mild CAT
	14:38:00		-39	1.7↑	0		-	220	40			330	-	On Third Leg of CAT Pattern
2	14:40:00		-39	1.7↑	0			220	40			330		Course Correction for Wind Drift
	14:41:30		-39	"	"	1°	-	220	40		←	315		CAT Sensor CH"A" 52GHZ Sensing ΔT
	14:42:30		-39	"	"	2°	-	"	"			"		"
	14:43:00		-39	"	"	2.5°	-	"	"			"		
	14:43:30	±.16	-39	"	"	3°	-	"	"			"	LM	Weak Cat But Continuous
	14:44:00	±.10	-39	"	"	3.5°	0.2	"	"			"	Li	CAT Becomes Intermittent, Discontinuous
	14:44:20	±.10	-37	"	"	3.8	2	"	"			"	"	"
	14:44:40	"	-34	"	"	4.2	4.2	"	"			"	"	"

FLT. PLAN: CAT SEARCH FLIGHT DATE: 14 FEB 1972

DOT/TSC-FLT #15

TABLE F-2. TEST DATA ON FLIGHT 15 (CONT'D)

CHANNEL NO.		11	4	13	10	9	7	8	5	3	14			
DATA SAM-PLE	TIME CODE GEN.	ACCEL VERT. G'S	TEMP AMB. °C	GYRO PITCH AIRCRAFT DEG	RADM INCLIN PITCH DEG	RADM CH"A" 52GHZ	RADM CH"B" 58GHZ	VEL KNOTS	ALT FEET	ACCEL LAT G'S	INCLIN ROLL DEG	AIRCRAFT HEADING COMPASS	CAT ENCTR	REMARKS
	H:M:S	PEAKS	ACTUAL			ΔT	ΔT		X1000			DEG	CLASS	
2	14:45:00	-	-34.5	1.7↑	0	4.8	5	220	40			315		Temperature Returning to Original Value
	14:45:20		-35	"	"	5	4.8	"	"			"		"
	14:45:40		-35	"	"	5	2.5	"	"			"		"
	14:46:00		-35	"	"	3	.7	"	"			"		"
	14:46:20		-37	"	"	0	0	"	"			"		"
	14:46:40		-39	"	"	-	-	"	"			315		Starting a Turn No Usable Data in Turns
3	14:48:30		-39	-	-	-	-	220	40			-		Turning Onto Leg #3 of CAT Pattern
	14:49:00	±.2	-38	1.7↑	0	.75	0	220	40			155	M-	On Leg #3
	14:50:00	±.16	-36	1.7↑	0	1.5	1°	"	"			155	Li	Light CAT Chops Continuous Temperature Change
	14:50:30	±.16	-35.5	"	"	2°	1.5	"	"			150	"	"
	14:51:00	±.1	-36	"	"	2.5	2.0	"	"			150	VLC	Very Light CAT Continuous
	14:51:30	±.1	-36.5	"	"	3	2	"	"			145	"	"
	14:52:00	±.1	-39	"	"	0	0	"	"			145	"	"
	14:53:00		-39	"	"	-	-	"	"			145		END PATTERN

FLT. PLAN: CAT SEARCH FLIGHT DATE: 14 APR 1972

DOT/TSC-FLT #15

Analyzing the test results, the CAT data should be eliminated as inaccurate from a sensing viewpoint because of the high angle pointing of the radiometer when the aircraft is in a climb attitude. This encounter was unique, however, since the data shows a temperature inversion from cold (- 44° C) to five degrees warmer (- 39°C) immediately after the aircraft leveled off at 40,000 ft. The 58 GHz radiometer channel (near sensing) had apparently sensed the anomaly on the way up to the operating altitude and supports the pilot's report of the temperature change.

The CAT 2 and CAT 3 encounters are similar except that they differ slightly in intensity and duration. Both the 52 GHz and 58 GHz channels detected the temperature anomalies before penetration and correlates with the temperature sensor data at the aircraft. The encounters were classified as of very low intensity and the data obtained is considered inadequate for a firm conclusion.

Flight 16 (2-15-72)

A study of preflight weather forecast suggested CAT of light to moderate intensity in the vicinity of Winslow and Tuba City, Arizona at 25,000 and 35,000 feet. Consequently, the flight was planned for this location at the higher altitude.

Referring to Figure F-5 it can be really seen that a number of CAT's prevailed as marked on the flight map and ranged in intensity from light to severe turbulence. The change in flight plan (in flight) was based on an airborne report of moderate CAT activities were continuous, increasing to high intensity then back down zero intensity. The CAT in the Phoenix vicinity was of this type and attained to a high intensity classified as severe. All the turbulence encounters above the light class were confirmed by the data given in Table F-3. This tabulated data, reduced from oscillograms, indicates the trend of the encounters in the "peak acceleration" column. The variations in ambient temperature at a constand altitudes bears this out as supporting data.

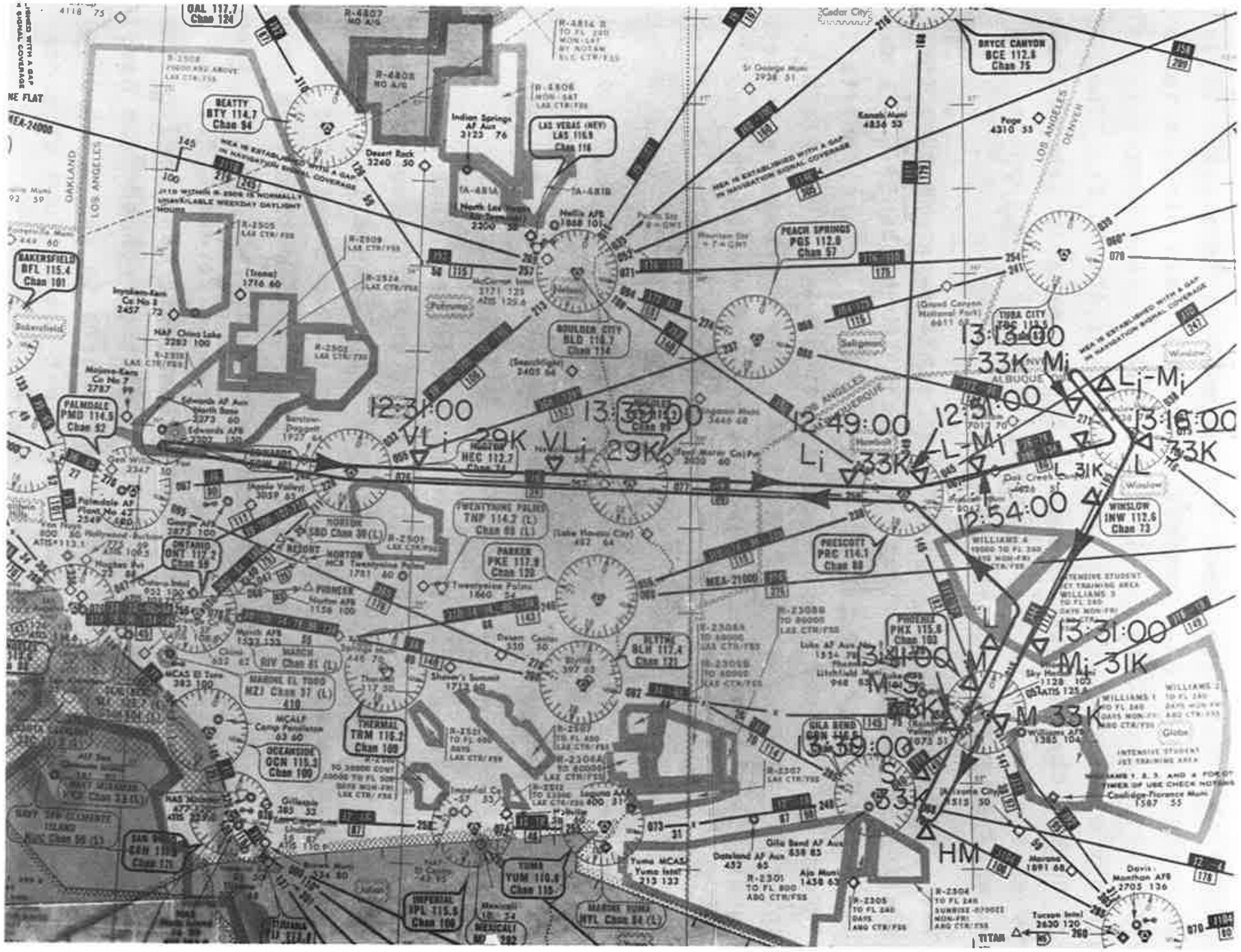

Figure F-5. CAT Search Flight; Flight 16; February 15,
Δ = CAT Encounter

TABLE F-3. TEST DATA ON FLIGHT 16

CHANNEL NO.		11	4	13	10	9	7	8	5	3	14			
TAPE FOOT-AGE	TIME CODE GEN.	ACCEL VERT. G'S	TEMP AMB. °C	GYRO PITCH AIRCRAFT DEG	RADM INCLIN PITCH DEG	RADM CH"A" 52GHZ	RADM CH"B" 58GHZ	VEL KNOTS	ALT FEET	ACCEL LAT G'S	INCLIN ROLL DEG	AIRCRAFT HEADING COMPASS	CAT ENCTR	REMARKS
		PEAKS	ACTUAL						X1000					
	12:01:00	0	-10	↑					10		→			Climb Out
	12:08:00	0	-21	↑				230	25					Level then Resumed Climb @ 12:15:00
	12:18:00	0	-28	0					29					Level Flight
	12:31:00	0	-35					224	29			062	VL	Very Light Turbulence Over Colorado River
	12:39:00	Noise	-36						29			063	VLi	Very Light Chops 36 Miles East of Needle, Calif.
	12:46:00	"	-31									068		Resumed Climb
	12:49:00	"	-35						33				Li	Light Chop Turbulence 12 miles West of Prescott, Ariz.
	12:50:30	±.16 ±.32	-35			NO DATA	NO DATA		33		→	060	Li to Mi	Light to Moderate Chops Prescott, Ariz.
	12:54:00	±.16 ±.32	-35						33		→	060	Li to Mi	" Continuous
	12:55:30	0	-35						33			060	-	End CAT 20 Miles Northeast of Prescott
	12:59:00 13:00:04	±.24	-35						33			060	Mi Li	Few Moderate Bumps Few Light Chops
	13:05:00		-38						33			060		Inbound to Winslow, Ariz.
	13:05:45		-42						33			060		"
	13:06:00		-35						33			060		"
	13:06:10		-42						33			060		"

FLT. PLAN: CAT SEARCH FLIGHT DATE: 15 FEB 1972

DOT/TSC-FLT #16

TABLE F-3. TEST DATA ON FLIGHT 16 (CONT'D)

CHANNEL NO.		11	4	13	10	9	7	8	5	3	14			
TAPE FOOT-AGE	TIME CODE GEN.	ACCEL VERT. G'S	TEMP AMB. °C	GYRO PITCH AIRCRAFT DEG	RADM INCLIN PITCH DEG	RADM CH"A" 52GHZ	RADM CH"B" 58GHZ	VEL KNOTS	ALT FEET	ACCEL LAT G'S	INCLIN ROLL DEG	AIRCRAFT HEADING COMPASS	CAT ENCTR	REMARKS
		PEAKS	ACTUAL						X1000			DEG		
	13:06:20		-35						33			060		
	13:06:30 13:07:30	±.16	-38 -35						33±.5				L	Temperature Variation With Altitude Change
	13:09:00	±.16 ±.32	-42						33		+	280	L to Mi	Changed Direction Over Winslow, Ariz.
	13:13:00	±.32	-38°						33		+	330	Mi	Moderate Chops-Partial CAT Pattern-20 Miles Northwest of Winslow
	13:15:00	±.16	-35					220	33			095	L to Mi	Back Inbound Winslow Again Light to Moderate Chops
	13:16:00	±.16	-35						33		+		L	Light Turbulence At Winslow Passing and Turing Right
	13:22:00		-35						31			205		Heading for Pheonix No Turbu-lence
	13:27:00	±0.2	-35			NO DATA	NO DATA		31			195	L	Light Turbulence 22 Miles South of Winslow
	13:28:00 13:31:00	±.16 ±.40	-35						31			195	Mi M	Moderate Chops to Moderate Turbulence
	13:32:00 13:35:00	±.55	-38						33			195	M	Passing Pheonix Turbulence Intensity Increasing and Constant
	10:38:00	±.60	-38 -40						33			195	HM	Moderate Turbulence get Heavy 40 Miles South of Pheonix
	13:39:30	±1.0	-35 -40						33			195 015	S	Turbulence Became Service 25 Miles South of Pheonix
	13:41:00	±.60	-38						33			015	HM	Heavy Moderate 8 Miles South of Pheonix
	13:48:00	±.32 ±.42							33			015	M	Passing Pheonix Turbulence Shows Dimishing
	13:54:00	±.16	-40						33			015	L	Diminished Turbulence 26 Miles Northweast of Pheonix
	13:55:00	0	-35						33			305	-	Inbound to Prescott and Base

FLT. PLAN: CAT SEARCH FLIGHT DATE: 15 FEB 1972

DOT/TSC-FLT #16

The Radiometric CAT sensor column show no data obtained. This was due to failure of the balancing noise source gas tube. Without the sky temperaute balancing feature of the sensor the received data signals become saturated and unusable for analysis. The failure was attributed to the tube exceeding its useful life.

Flight 17 (2-18-72)

The usual weather observations were made at the Edwards AFB, Weather Station. The study showed possible wind shear, 40-70 knots near Flagstaff Arizona at 35,000 to 40,00 feet. The wind shear was considered insufficient but coupled with a trough running North and South through Central Arizona, a twenty-five percent possibility of turbulence was predicted. The flight was planned for 35,000 feet and as shown on the flight chart, Figure F-6 two moderate CAT's were encountered. The first encounter, immediately after departure and during climb out, could not be analyzed because of the attitude of the aircraft and the low altitude. Later in flight, a light to moderate CAT was encountered during a CAT pattern run at Peach Springs, Arizona, at 33,000 feet. These encounters are also shown on the Figure F-6 flight chart along with other marked light turbulence which produced insignificant data for consideration.

The light to moderate encounter apparently contained a temperature anomaly that was sensed by the radiometric CAT sensor prior to penetration and confirmed the encounter. A plot showing the progression of this anomaly, presented in Figure F-7, indicates the earlier sensing (50 miles) by channel "A" and later sensed by both channel "B" and the aircraft thermocouple. The analyzed values taken from oscillograms are also tabulated in Table F-4.

Flight 18 (4-19-72)

The weather station forecast for ETD-10 hours was reported moderate to severe turbulence over Peach Springs, Arizona at 20,000-24,000 feet. Moderate turbulence was also forecasted over North Central Arizona at 28,000-38,000 feet. At ETD-2 hours the weather data indicated a jet stream core over Winslow, Arizona at

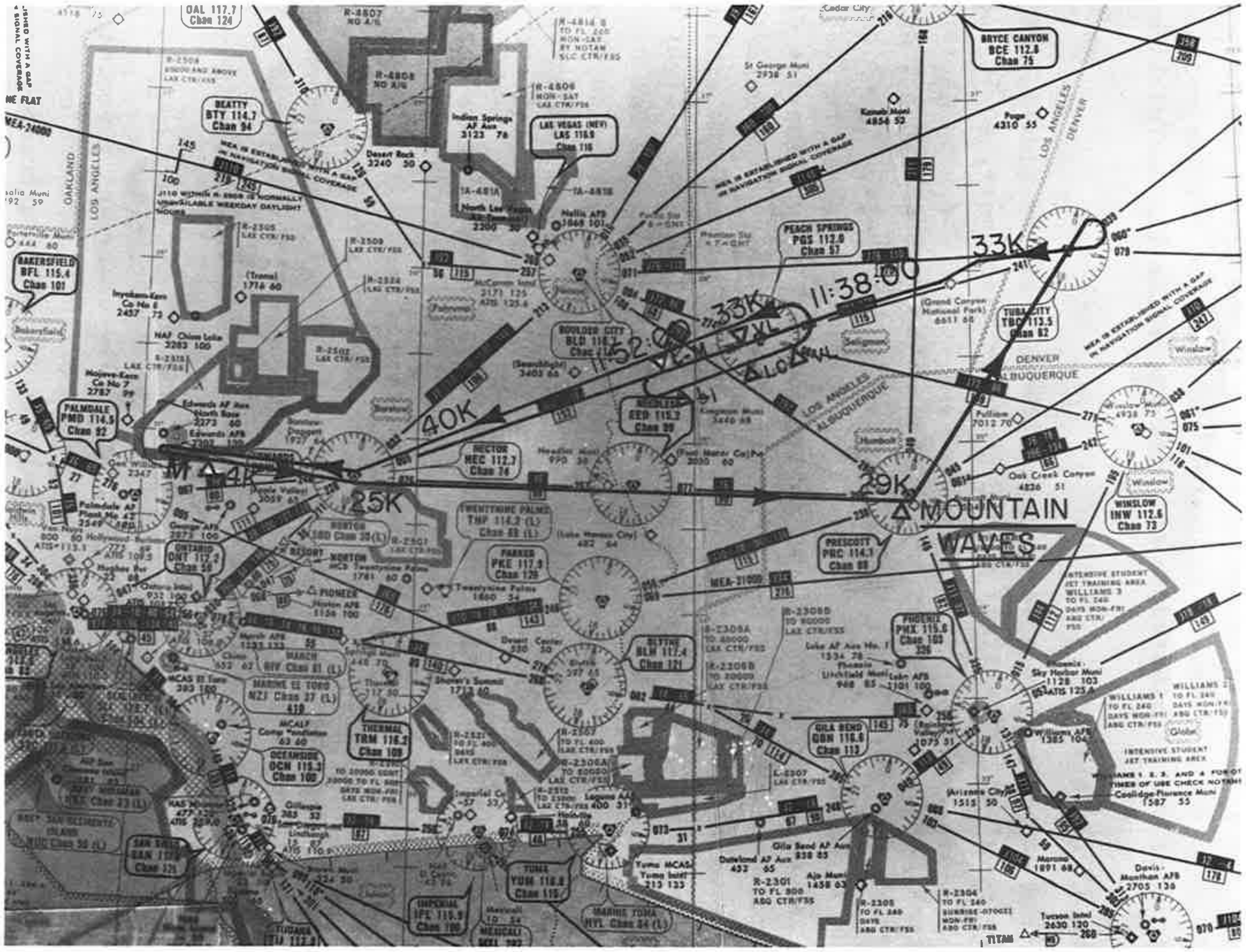

Figure F-6. CAT Search Flight; Flight 17; April 18, 1972
Δ = CAT Encounter

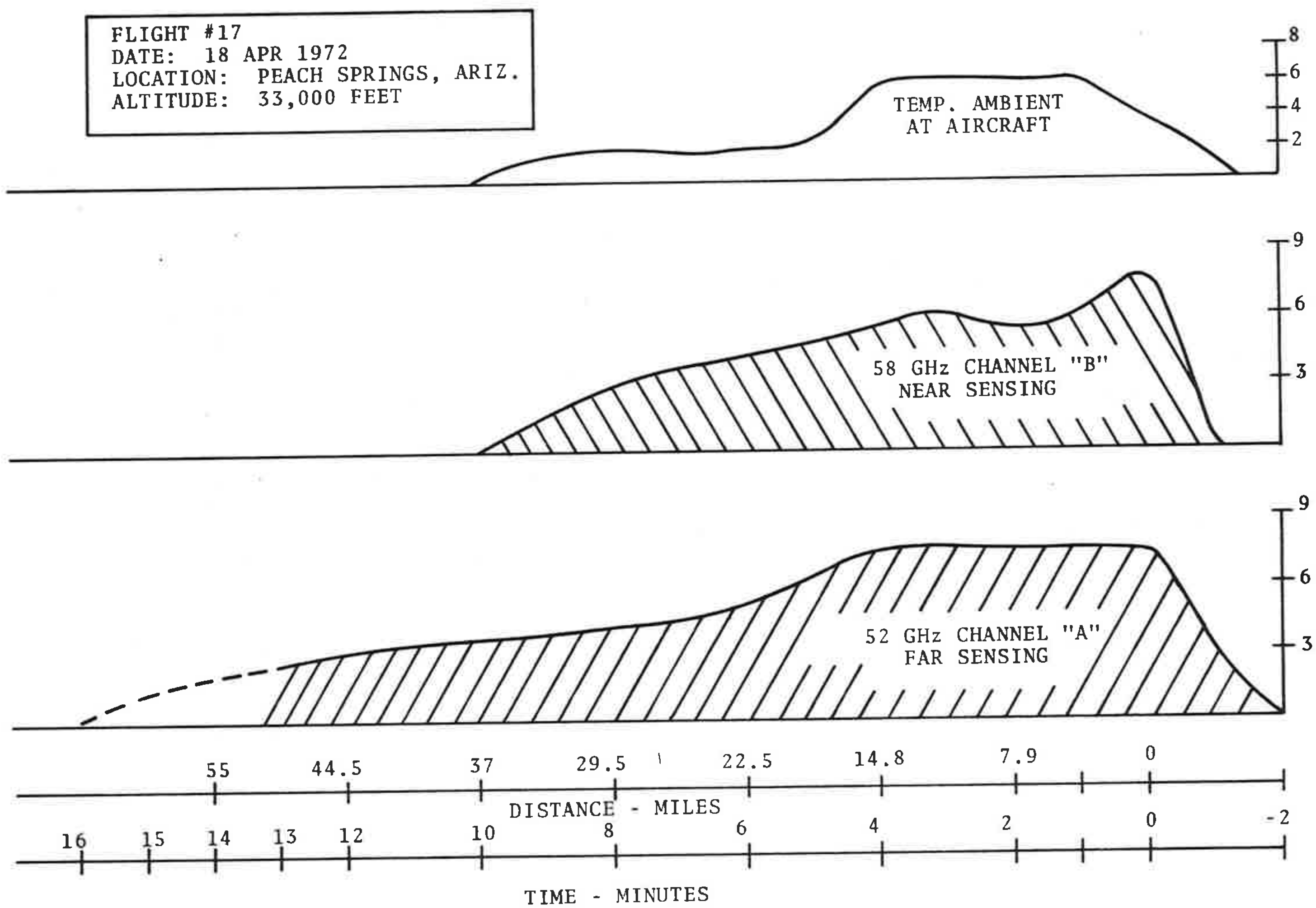

Figure F-7. CAT Encounter - ΔT; Flight 17; April 18, 1972

TABLE F-4. TEST DATA ON FLIGHT 17

CHANNEL NO.		11	4	13	10	9	7	8	5	3	14			
DATA SAM-PLE	TIME CODE GEN.	ACCEL VERT. G'S	TEMP AMB. °C	GYRO PITCH AIRCRAFT DEG	RADM INCLIN PITCH DEG	RADM CH"A" 52GHZ	RADM CH"B" 58GHZ	VEL KNOTS	ALT FEET	ACCEL LAT G'S	INCLIN ROLL DEG	AIRCRAFT HEADING COMPASS	CAT ENCTR	REMARKS
	H:M:S	PEAKS	ACTUAL			ΔT	ΔT		X1000			DEG	CLASS	
1	10:26:00	±.38		4 ↑	2.3↑	-	-		3			075	M	Moderate CAT While in Climb
	10:27:00	±.50	+10	↑	↑	-	-	290	4			075	M	In Moderate CAT
	10:27:30	±.25		↑	↑	-	-		6			075	L	Passing Through Turbulence
	10:28:30	-	+4	↑	↑	-	-	290	10			085		
2	11:38:00	-	-34	2 ↑	↑0.3	+2.5		215	33	-	-	239		20 Miles Northeast of Peach Springs, Ariz.
	11:39:00	-	-34	2 ↑	↑0.3	+3			33			228		Start CAT Pattern
	11:41:00	-	-34	1.7↑	0	+3.2			33			228		
	11:43:00	-	-32	1.7↑	0	+4.5	+1.5	220	33			228		
	11:44:00	-	-32	1.7↑	0		+3		33			228		
	11:45:00	-	-32	1.7↑	0		+4		33	-	-	228		
	11:46:00	-	-32	1.7↑	0	+5.7	+4.5		33			228	VL	15 Miles Southwest of Peach Springs Very Light CAT Insignificant
	11:47:00	-	-31.8	1.7↑	0	+6	+5		33			228		
	11:48:00	-	-28	1.7↑	0	+7.5	+5.5		33			228		

FLT. PLAN: CAT SEARCH FLIGHT DATE: 18 APR 1972

DOT/TSC-FLT #17

TABLE F-4. TEST DATA ON FLIGHT 17 (CONT'D)

CHANNEL NO.		11	4	13	10	9	7	8	5	3	14			
DATA SAMPLE	TIME CODE GEN.	ACCEL VERT. G'S	TEMP AMB. °C	GYRO PITCH AIRCRAFT DEG	RADM INCLIN PITCH DEG	RADM CH"A" 52GHZ	RADM CH"A" 58GHZ	VEL KNOTS	ALT FEET	ACCEL LAT G'S	INCLIN ROLL DEG	AIRCRAFT HEADING COMPASS	CAT ENCTR	REMARKS
	H:M:S	PEAKS	ACTUAL			ΔT	ΔT		X1000			DEG	CLASS	
	11:49:00		-28	1.7↑	0	+7.5	+6	220	33			228		
	11:50:00		-28	1.7↑	0	+7.5	+5.5		33			228	L-M	
	11:51:00		-28	1.7↑	0	+7.5	+6		33			228	L-M	
	11:52:00		-28	1.7↑	0	+7.5	+5.5	220	33			228	L-M	Light To Moderate CAT - 40 Miles South of Peach Springs
	11:53:00		-30	1.7↑	0	+4.5	-		33			228		
	11:54:00		-34	1.7↑	0	-	-		33			228		
	11:59:00		-34	1.7↑	0	-	-	220	33			070	Li	Light Chops Turbulence Inbound to Peach Springs
	12:04:00		-35	1.7↑	0	-	-		33			070	LC	Continuous LGT CAT Peach Springs
	12:12:00		-35	1.7↑	0			220	33			070	VL	Very Light Turbulence Northeast Peach Springs
	12:15:00		-	1.7↑	0				33			225	-	Returning to Base End Pattern

FLT. PLAN: CAT SEARCH

FLIGHT DATE: 18 APR 1972

DOT/TSC-FLT #17

30,000 feet and a trough line running down into souther California. The test pilot confirmed this jet stream inbound to Prescott and reported it as smooth at 31,000 feet.

Six turbulences encountered enroute ranging from very-light intermittent to light shown on the flight course chart, Figure F-8 and Table F-5. The data analyzed from Table F-5 and the oscillographs indicate little or no variation in the parameters. The CAT sensor responded to lapse rate but was otherwise constant during level flight at a constant altitude therefore, it was concluded that the turbulence was too low in intensity (±0.16g's max peak acceleration) for detection.

Flight 19 (4-20-72)

Preflight weather predictions for this flight indicated less than a twenty-five percent chance of turbulence in the upper atmosphere. Significant winds and temperature variations for low intensity turbulence was noted in the Northwest Arizona, Southwest Utah, and Southeast Nevada triangle at about 40,000 feet.

The flight was planned for 39,000 feet and 41,000 feet through Winslow, Arizona and Bryce Canyon, Utah as shown on Figure F-9.

Five encounters were reported by the pilot ranging from very light intermittent to moderate intermittent, also marked on Figure F-9.

A good moderate turbulence encounter was reported by the test pilot about 40 miles outbound from Bryce Canyon, Utah. From a data analysis of this point the following was deduced.

Duration:	30 seconds
ΔT ambient:	2°C
Acceleration:	±.30g
Velocity Increase:	10 knots
Altitude Increase:	600 feet in 7 seconds
Radiometer 58 GHz ΔT:	2.5°K
Radiometer 52 GHz ΔT:	2.5°K

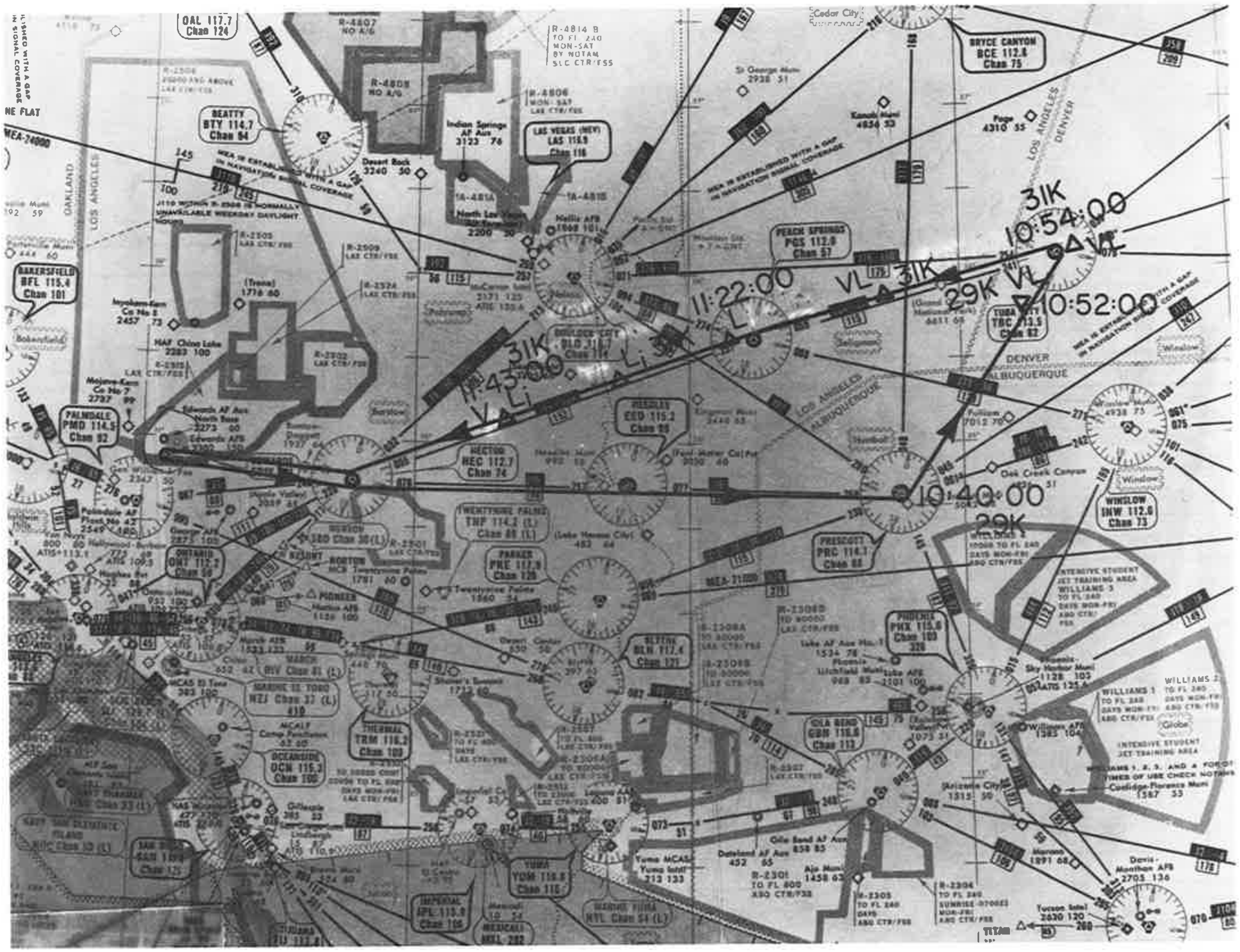

Figure F-8. CAT Search Track Chart; Flight 18; Number 18, April 19, 1972
Δ = CAT Encounter

TABLE F-5. TEST DATA ON FLIGHT 18

CHANNEL NO.		11	4	13	10	9	7	8	5	3	14				
TAPE FOOT-AGE	TIME CODE GEN.	PEAK ACCEL VERT. G'S	TEMP. AMB. °C ACTUAL	GYRO PITCH AIRCRAFT DEG	RADM INCLIN PITCH DEG	RADM CH"A" 52GHZ	RADM CH"B" 58GHZ	VEL KNOTS	ALT FEET	ACCEL LAT G'S	INCLIN ROLL DEG	MACH NO.	AIRCRAFT HEADING COMPASS	CAT ENCTR.	REMARKS
	9:58:30														Flight Departure
	9:59:00		0	+7°	+5.3			250	10	-					
	10:01:00		-15					245	20	-			077°		Climbing
	10:05:00		-24	+1.7°	0			220	29	-			077°		Level Flight
	10:40:00		-29	+2.0°	+0.3			220	29	-			084°		Over Prescott, Ariz.
	10:52:00	±0.1		+1.5°	-0.2			220	29				015°	IVL	20 Miles South of Tuba City. Very Light Turbulence
	10:54:30	±0.1						220	31					IVL	Over Tuba City, Ariz. V. L. Turb
	11:12:00	±0.05	-31	+1.7°	0			220	31				238°	IVL	West of Tuba City V.L. Turb
	11:22:30	±0.16	-30	+1.7°	0			220	31				230°	IL	Peach Springs. Ariz. Light Turb
	11:35:00	±0.08	-29	+1.7°	0			220	31				230°	ILi	60 Miles West Peach Spring Intermittent Turb
	11:43:00	±0.04	-29					220	31				235°	IVLi	50 Miles East Hector, Calif. Intermittent Turb
	11:51:00		-29	+2.0	+0.3			220	40	-		.73	235°		Over Hector
			-37						48	-			330°		
	12:22:00		-37		+2.8			164	48	-			150°		Owens Lake Region; Turb Trace-Ran Pattern
															Return to Base
	12:40:00														Arrival at Base

FLT. PLAN: CAT SEARCH FLIGHT DATE: 19 APR 1972

DOT/TSC-FLT #18

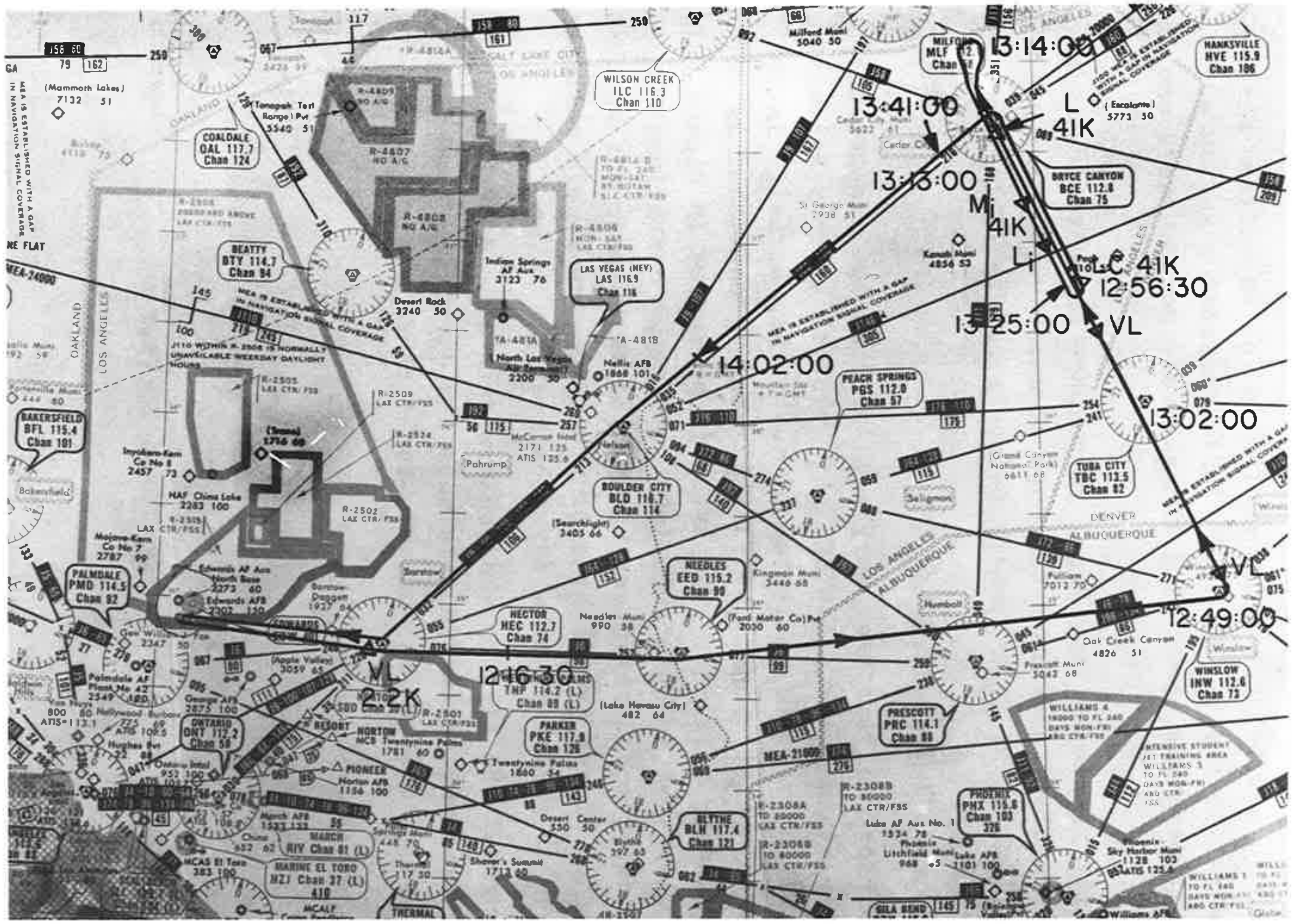

Figure F-9. CAT Search Track Chart; Flight 19; April 20, 1972
Δ = CAT Encounter

The radiometer 58 GHz channel also indicated the same ΔT one minute before penetration (about 10 miles). The 52 GHz channel (for sensor) data indicated slight pitch changes within 5 minutes of the CAT and could not be accurately evaluated for an earlier detection. Upon penetration the 52 GHz channel did register a sudden very cold sky temperature confirming the aircraft nosed upward one degree.

For the remaining four light turbulence encounters as with all other similar encounters the data produced variations too small for evaluation. The data Summary is contained in Table F-6.

Flights 20 and 21 (4-21; 24-72)

Both these flights were very similar from the weather and flight plan stand point. A preflight study of weather forecast and airborne flight reports indicated no turbulence activity in the troposphere. Nonetheless, the flights were accomplished as CAT search secondary missions. The track is presented in Figure F-10. The detection system was placed in a continuous operational mode for the total time in the event unexpected turbulence was encountered. The pilot did report two light encounters but these were evaluated as very low intensity minimum duration mountain waves.

Throughout the flights the sensors data showed continual changes in aircraft attitude, altitude and direction therefore, the data was considered as unusable for further processing.

TABLE F-6. TEST DATA ON FLIGHT 19

CHANNEL NO.		11	4	13	10	9	7	8	5	3	14				
TAPE FOOT-AGE	TIME CODE GEN.	ACCEL VERT. G'S	TEMP AMB. °C ACTUAL	GYRO PITCH AIRCRAFT DEG	RADM INCLIN PITCH DEG	RADM CH"A" 52GHZ	RADM CH"B" 58GHZ	VEL KNOTS	ALT FEET	ACCEL LAT G'S	INCLIN ROLL DEG	MACH NO.	AIRCRAFT HEADING COMPASS	CAT ENCTR.	REMARKS
						ΔT	ΔT		X1000						
	11:55:00														Flight Departure
	12:01:00		+10	7°+	5.3°+			260	10						
	12:05:00								18						Climbing
	12:07:00	±0.05							23						Climbing Turb-Slight Trace
	12:11:00	0	-24	3°+	1.3°+				30						Passing Hector, Calif.
	12:16:30	0	-35	2°+	.3°+			220	37						60 Miles West of Needles, Calif Clear Sky
	12:43:00	0	-37	2°+	.3°+			220	37				070°		43 Miles West of Winslow, Ariz. Calm
	12:49:00	±0.06	-35	2.5°+	.8°+			220	37				070°		Over Winslow Some Light Turb
	12:56:30	±0.04	-34	3°+	1.3°+			205	41				313°	TRACE	Trace Light Turb 36 Miles South of Tuba City
	12:54:00	±0.10	-32	2°+	.3°+				41				313°	OCCAS	Occasional Light 18 Miles South of Tuba City
	13:02:00	±0.13	-32	2°+	.3°+			215	41				313	TRACE	Turb Could be Aircraft Buff Over Tuba City
	13:07:00	±0.12		2.5°+	.8°+			215				.73	318	L	Bryce Canyon, Utah Light Turb-Pattern Row
	13:13:00	±0.3		2.7 +	1°+	2.5°	2.5°	216	41				138	Mi	Level Flight 34 South of BC Moderate Turbulence 30 Seconds
	13:40:00	±0.3	-31	2.7 +	1°+	2.5	2.5	216	41				138		Mod Turbulence Dissipated
	13:20:00	±0.08	-31	2°+	.3°+				41				1	Li	55 Miles South of Bryce Occasional Light Turbulence

FLT. PLAN: CAT SEARCH FLIGHT DATE: 20 APR 1972

DOT/TSC-FLT #19

TABLE F-6. TEST DATA ON FLIGHT 19 (CONT'D)

CHANNEL NO.		11	4	13	10	9	7	8	5	3	14				
TAPE FOOT-AGE	TIME CODE GEN.	ACCEL VERT. G'S	TEMP AMB. °C	GYRO PITCH AIRCRAFT DEG	RADM INCLIN PITCH DEG	RADM CH"A" 52GHZ	RADM CH"B" 58GHZ	VEL KNOTS	ALT FEET	ACCEL LAT G'S	INCLIN ROLL DEG	MACH NO.	AIRCRAFT HEADING COMPASS	CAT ENCTR.	REMARKS
	13:23:00														Started 180° Turn to Northwest
	13:27:00	±0.08	-30	2°↑	.3°↑			215	41				316	LC	Light Continuous Turbulence 80 Miles South of Bryce C.
	13:35:00	±0.04	-30					215	41				237	Li	CAT Pattern Completed at Bryce C.
	13:41:00	0	-32					215	41				216		12 Miles Southwest of Bryce C No Turbulence
	13:57:00	0	-35	2°↑	.3°↑			215	41				216		61 Miles Northeast Las Vegas No Activity
	14:02:00	0	-34.5	2°↑	.3°↑			216	41				228		33 Miles Northeast Las Vegas Level Net
	14:31:00	0	-38	4.5°↑	2.8°↑			262	49				270		Over Barstow, Calif No Tur-bulence
	14:40:00	-	-16					220	22				280		Reduced Altitude
	14:43:00	-	-9	11°↑	9.3 ↑				18						
		-	-13	9°↑	7.3 ↑			220	22				100		Returning to Base
	14:55:00	-													ATA @ Base

FLT PLAN: CAT SEARCH FLIGHT DATE: 20 APR 1972

DOT/TSC-FLT #19

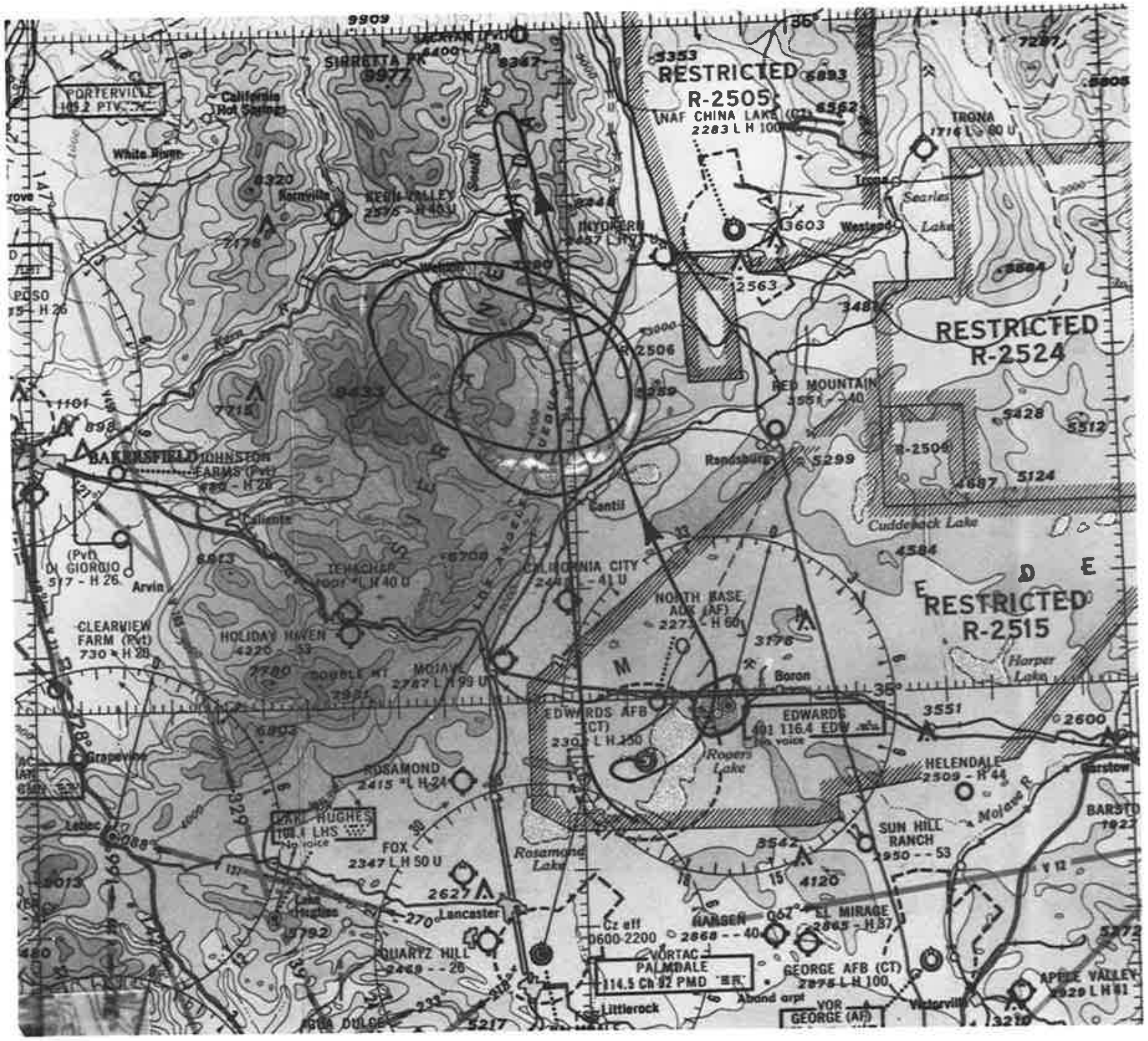

Figure F-10. CAT Search Track Chart; Flights 20 and 21; April 21 and 24, 1972. Δ = CAT Encounter

APPENDIX G

PHYSICAL DATA OF AIRBORNE EQUIPMENT

1. Dimensions

Flight System Package	Height	- 17 inches
	Width	- 22 inches
	Depth	- 34 inches
Radiometric Sensor	Antenna Face	- 17 inches square
	Antenna Diam.	- 12 inches
	Depth	- 13 inches
Instrumentation Pod	Length	- 170 inches
	Greatest Diam.	- 32 inches

2. Weights

Flight System Package	156.0
Pod (C.G.) Balance Weight	125.0
Instrumentation Pod Empty	217.5
Right Wing Total Weight	498.5 lbs.

3. Power Requirements

Gyro Power	- 400 cycle
Other Electronics	28 VDC
Total Power	200 Watts

APPENDIX H

COPY OF CAT DETECTOR PATENT

United States Patent

Haroules et al.

[15] **3,665,467**

[45] **May 23, 1972**

[54] **CLEAR AIR TURBULENCE DETECTOR**

[72] Inventors: **George G. Haroules,** Lexington; **Wilfred E. Brown, III,** Acton; **Harold I. Ewen,** Weston; **Arthur E. Lilley,** Belmont; **Ralph D. Kodis,** Newton, all of Mass.

[73] Assignee: **The United States of America as represented by the Administrator of the National Aeronautics and Space Administration**

[22] Filed: **Nov. 19, 1969**

[21] Appl. No.: **877,990**

[52] **U.S. Cl.** ....**343/100 ME,** 73/355, 325/363, 343/112 D

[51] **Int. Cl.** **G01w 1/00**

[58] **Field of Search** ....343/100 ME; 73/355; 325/363

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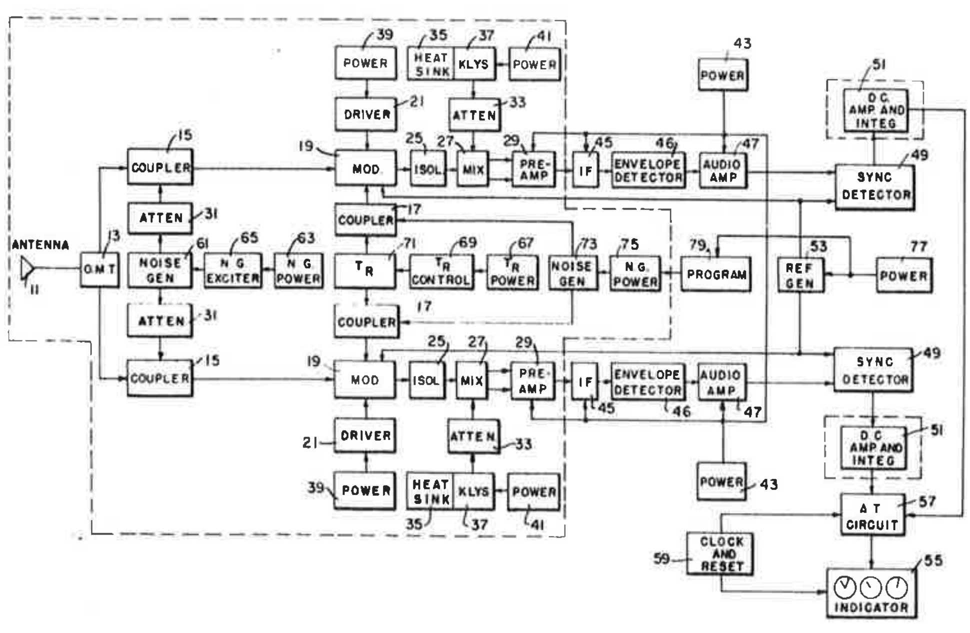
Primary Examiner—Samuel Feinberg
Assistant Examiner—Richard E. Berger
Attorney—Herbert E. Farmer, John R. Manning and Garland T. McCoy

[57] **ABSTRACT**

This disclosure describes an apparatus for warning the pilot of an aircraft of a region of clear air turbulence. A multi-channel radiometric sensor mounted on the aircraft detects both the ambient temperature of the air and any temperature anomaly that is present along the forward flight path. In those cases where temperature anomalies are associated with the presence of a clear air turbulence region, the invention provides means for remotely sensing these temperature-anomalies through the application of a unique radiometric technique. By the detection of difference temperatures between a minimum of two channels, the invention provides a means for indicating the existence of a temperature anomaly indicative of clear air turbulence region. In addition, the distance from the aircraft to the anomalous temperature region is directly determined from the output indication of the radiometric sensor channels. The distance between the clear air turbulence region and the aircraft is determined by utilization of at least two observing frequencies which have known absorption coefficients of different values.

7 Claims, 6 Drawing Figures



CLEAR AIR TURBULENCE DETECTOR

ORIGIN OF THE INVENTION

The invention described herein may be manufactured and used by or for the United Stages Government for governmental purposes without payment of any royalty thereon or therefor.

BACKGROUND OF THE INVENTION

Clear air turbulence (CAT) regions are a hazard to modern aircraft because the effects of moving through a CAT region may result in severe structural damage to the aircraft. In fact, passing through a CAT region may even result in the loss of the aircraft. CAT can be generated by atmospheric processes that are markedly different from each other in terms of their physical and dynamic characteristics. Some of these atmospheric processes are predictable and, consequently, CAT caused by them is detectable. For example, CAT associated with mountain waves is predictable from the data obtained and disseminated by weather stations. Similarly, CAT due to strong vertical convection currents usually found in the proximity of large cumulus clouds is detectable using weather radar. However, other CAT regions are not easily detectable. For example, the CAT which occurs in jet stream frontal regions is not easily detectable.

It will be appreciated from the foregoing description of the effects of CAT that it is desirable to provide a system that detects CAT regions and warns an aircraft pilot of their existence so that the pilot can take evasive action.

Therefore, it is an object of this invention to provide a new and improved apparatus for detecting clear air turbulence regions by detection of their related temperature anomaly.

It is also an object of this invention to provide an apparatus for warning a pilot of a clear air turbulence region that is suitable for use on aircraft traveling faster than the speed of sound.

It is another object of this invention to provide an apparatus for warning a pilot of a clear air turbulence region that is low in power consumption, low in complexity and low in weight, making it suitable for use on modern aircraft.

It is still another object of this invention to provide an apparatus for measuring the range to and temperature anomaly associated with a clear air turbulence region, interpreting the measured data, and warning the pilot of the occurrence of the clear air turbulence region in sufficient time for the pilot to avoid the clear air turbulence region.

SUMMARY OF THE INVENTION

In accordance with a principle of this invention, an apparatus for detecting atmospheric temperature anomalies associated with regions of clear air turbulence is provided. The apparatus comprises a multifrequency radiometric receiver, an antenna, and a signal processing system. The radiometric sensor by means of its antenna detects a temperature difference in the form of a microwave signal when the sensor system is mounted in an aircraft and the aircraft is moving in a forward direction toward the temperature anomaly. The system uses two or more different frequencies that are associated with the different absorption coefficients of gases in the atmosphere. The technique will also detect density anomalies when there is no temperature anomaly. Utilizing the characteristic of molecular resonance in terms of absorption coefficients over small bandwidths, allows the sensor to simultaneously observe the thermal radiation of the atmosphere over a large dynamic range of absorption coefficients determined by the appropriate selection of frequency. The use of atmospheric oxygen as such a gas is advantageous because of its well defined molecular resonances and line structure. That is, at a particular flight altitude a desired absorption coefficient in the range from 0.5 db/km to several db/km can be chosen by merely selecting the frequency of observation.

The radiometric sensor looking forward along the flight path detects temperatures consisting of two components — the ambient temperature, T_o, along the flight path, plus a difference temperature, ΔT_c, relative to the ambient temperature. The values of ΔT_c observed at frequencies with different absorption coefficients differ in magnitude, depending on the horizontal range to the CAT region. The lower the absorption coefficient, the greater the range at which a ΔT_c is detected. The higher the absorption coefficient, the shorter the range. As the aircraft approaches the CAT region, the frequency of observation corresponding to the highest absorption coefficient ultimately provides a larger value of ΔT_c than all other frequencies of observation, even though the frequency corresponding to the lowest absorption coefficient provides the first detection of a temperature difference ΔT_c relative to the ambient.

An appropriate indicating means is connected to the output of the multifrequency sensor to provide the pilot with an indication of the time before encountering the region of clear air turbulence. The indicating means also indicates the distance from the aircraft to the region of clear air turbulence.

In accordance with a still further principle of this invention, the multifrequency radiometric sensor is balanced by noise injection so that only temperature differences are sensed when it is being used to determine the range to the clear air turbulence. That is, the radiometer channels are adapted to sense only temperature differences at the frequencies of operation of each of the channels, not temperatures on an absolute scale.

It will be appreciated by those skilled in the art and others that the invention is a rather uncomplicated apparatus for detecting regions of atmospheric temperature anomalies along the flight path of an aircraft. A multifrequency radiometer having a balanced input is utilized to sense these temperature anomalies along the flight path of the aircraft. The use of a multifrequency system results in a sensor that senses the ambient temperature along the flight path, as well as anomalous temperature regions forward of the aircraft along the flight path. In addition, the power requirements of a radiometer fall within the power capabilities of a modern aircraft power plant. Further, a radiometer beam is not harmful to the eyes of pilots of other aircraft as is a laser beam, for example.

BRIEF DESCRIPTION OF THE DRAWINGS

The foregoing objects and any of the attendant advantages of this invention will become more readily appreciated as the same becomes better understood by reference to the following detailed description when taken in conjunction with the accompanying drawings wherein:

FIG. 1 is a pictorial diagram utilized to describe the ranging theory of operation of the invention;

FIG. 2 is a graphical diagram of the normalized response of a radiometric sensor to a step temperature anomaly as a function of range;

FIG. 3 is a graphical diagram of the normalized response of a radiometric sensor to a ramp temperature anomaly as a function of range;

FIG. 4 is a graphical diagram of the normalized response of a radiometric sensor to an exponential temperature anomaly as a function of range;

FIG. 5 is a functional block diagram of a preferred embodiment of the invention; and

FIG. 6 is a functional block diagram of a modified absolute radiometric mode or temperature difference mode.

DESCRIPTION OF THE PREFERRED EMBODIMENT

Prior to describing the preferred embodiment of the invention, the following description of the theory of the operation of the ranging aspects of the invention is presented.

To illustrate the range capability of a radiometric temperature probing system, first consider one frequency of observation (one channel) in which the atmospheric attenuation coefficient determined by the observing frequency is constant throughout the ray path. The antenna temperature for this condition is:

$$T_A = (1 - 1/L)T_o \qquad 1$$

where T_A = the antenna temperature;

T_o = the ambient temperature along the horizontal flight path at the flight altitude; and

L = the total attenuation of the atmosphere along the flight path

The total attenuation L in the above equation must be expressed in a numerical value. It is conventional to refer to the attenuation of the atmosphere in the units of db/km. For example, if the attenuation is one db per kilometer, then in a path 20 km long, forward of the aircraft, the value of L is 20 db (numerical value = 100); and, the value, T_A, sensed by the radiometer from this 20 km path, is 99 percent of the value of the ambient temperature at the flight altitude. It is apparent from this simple example that if there is no temperature anomaly along the flight path, then the temperature sensed by the radiometer is the ambient temperature along the flight path.

Next, consider the case in which a temperature anomaly occurs over a small range increment forward of the aircraft. This condition is shown in simplified form in FIG. 1. The radiometer is shown on the far left-hand side of the diagram. The range to the CAT region is S_1. The extent of the CAT region is S_2–S_1. The column of air beyond the CAT region extends to infinity (for all practical purposes in this analysis).

For the first step in the analysis, assume that the temperature is constant along the entire flight path; i.e., that a CAT temperature anomaly does not exist. However, for ease of analysis, the individual temperature contributions from each of the three regions is hereinafter developed.

L_1 = the total attenuation over the path S_1;

L_2 = the total attenuation over the path S_2–S_1; and

L_3 = the total attenuation beyond the CAT region.

Then, the contribution to the antenna temperature from the region S_1 is:

$$T_{S_1} = \left(1 - \frac{1}{L_1}\right) T_o \qquad (2)$$

obtained directly from Equation (1). The temperature radiated by the CAT region ($S_2 - S_1$) is:

$$T_{S_2} = \left(1 - \frac{1}{L_2}\right) To \qquad (3)$$

However, this radiated temperature is attenuated as it passes through the path S_1; hence, the temperature of the CAT region observed at the sensor is:

$$T_{S_2} = \left(1 - \frac{1}{L_2}\right) \frac{To}{L_1} \qquad (4)$$

In a similar manner, the temperature radiated by the region beyond the CAT measured at the far boundary of the CAT region is:

$$T_{S_x}' = \left(1 - \frac{1}{L_3}\right) To \qquad (5)$$

Since this region is considerably greater in extent than the range increments S_1 and S_2, the temperature radiated by this region in the direction of the sensor measured at the far boundary of the CAT region will be equal to the ambient, To. That is:

$$T_{S_x}' = To \qquad 6$$

However, the temperature contribution from this region, measured at the sensor, also suffers the attenuation of the CAT region ($S_2 - S_1$) and the region S_1; hence, the contribution at the sensor is:

$$T_{S_1}, T_{S_2}, \text{ and } T_{S_x}. \qquad 7$$

Therefore, the temperature at the sensor consists of three components: T_{S_1}, T_{S_2}, and T_{S_x}. Summing up and simplifying Equations **2**, **4**, and **7** provides the following result:

$$T_1 = \left(1 - \frac{1}{L_1}\right) To + \left(1 - \frac{1}{L_2}\right) \frac{To}{L_1} + \frac{To}{L_1 L_2}$$

$$To - \frac{To}{L_1} + \frac{To}{L_1} - \frac{To}{L_1 L_2} + \frac{To}{L_1 L_2} = To \qquad (8)$$

As anticipated, the antenna temperature equals the ambient temperature along the flight path consistent with the assumed condition that there was no temperature anomaly in the region $S_2 - S_1$.

Now assume a temperature anomaly ΔTo is in the region $S_2 - S_1$. This change in the analysis is accommodated by noting that T_{S_2} now takes the form:

$$T_{S_2} = \left(1 - \frac{1}{L_2}\right) \frac{To + \Delta To}{L_1} \qquad (9)$$

which can be rewritten in the form:

$$T_{S_2} = \left(1 - \frac{1}{L_2}\right) \frac{To}{L_1} + \left(1 - \frac{1}{L_2}\right) \frac{\Delta To}{L_1} \qquad (10)$$

Since the second term in Equation **10** represents the only difference in the summation, relative to the prior condition in which the temperature was considered to be constant throughout the horizontal flight path, then it is apparent that the antenna temperature now sensed by the radiometer takes the form:

$$T_1 = To + \left(1 - \frac{1}{L_2}\right) \frac{\Delta To}{L_1} \qquad (11)$$

Equation 11 can be rewritten in the form:

$$T_1 = To + \frac{1}{L_1}\left[\left(1 - \frac{1}{L_1}\right) \Delta To\right] \qquad (12)$$

Hence, the observed antenna temperature at the sensor consists of two terms, the ambient temperature To and the differential temperature radiation of the CAT region, shown in the bracketed term and related directly to Equation **1**, attenuated by the passage of this radiation through the region S_1 which introduces a loss L_1.

Summarizing, Equation **12** can be rewritten in the form:

$$T_A = To + \Delta T_C \qquad 13$$

where:

$$\Delta T_c = \frac{1}{L_1}\left[\left(1 - \frac{1}{L_2}\right) \Delta To\right] \qquad (14)$$

Therefore, the observed differential temperature, relative to the ambient temperature is a function of:

a. the temperature anomaly in the CAT region, ΔTo,

b. the extent in range ($S_2 - S_1$), of the CAT region and the atmospheric attenuation associated with the CAT region as reflected by the value of L_2; and,

c. the range to the CAT region S_1 from the radiometer and the atmospheric attenuation associated with this path as reflected by the value of L_1.

It should be noted at this point that the values of L_1 and L_2 are not only range dependent, but also dependent on the absorption coefficient (α in db/km) of the medium which is in turn dependent on the frequency of observation. Reference is made to an article entitled, "The Microwave Spectrum of Oxygen in the Earth's Atmosphere," by M. L. Meeks and A. E. Lilley, in Volume 68, No. 6 Edition of the Journal of Geophysical Research, dated Mar. 15, 1963, for a discussion of the dependency of the atmospheric absorption coefficient on frequency of observation at frequencies near 60,000 GHZ.

The following mathematical example more clearly demonstrates the ability of a radiometer to detect a temperature anomaly in range, as a consequence of the difference observed in the values of ΔT_c as a function of the frequency of observation; i.e., absorption coefficient.

Consider the following conditions:

a. $\Delta To = 10°K$

b. $\alpha A = 0.1$ db/dm = attenuation at one frequency

c. $\alpha B = 1.0$ db/km = attenuation at the second frequency

d. Extent of the CAT region ($S_2 - S_1$) = 10 km

Using the foregoing values, the temperature radiated by the CAT region at the two frequencies of observation can be computed. The radiated temperature is given by the term in brackets in Equation 14.

These values are listed in Table I.

TABLE I

αdb/km	(S_2-S_1) km	L_2(db)	L_2(no)	$[(1-1/L_2)\,\Delta To^1$
αA=0.1	10	1.0	1.26	2°K
αB=1.0	10	10.0	10.0	9°K

The value of ΔT_c associated with the CAT anomaly as observed at the sensor can now be computed as a function of range to the CAT region by merely introducing the appropriate attenuation of 2°K and 9°K signals over the range S_1, remembering, of course, that the attenuation value in either case in db/km must be applied. These values are listed in Table II:

TABLE II

Range (km)	αA = 0.1db/km L_1(db)	L_1(no)	ΔT_c	αB = 1.0db/km L_1(db)	L_1(no)	ΔT_c
10	1.0	1.26	1.6°K	10.0	10.0	0.9°K
50	5.0	3.15	0.65°K	50.0	10^5	10^{-4}°K
100	10.0	10.0	0.20°K	100.0	10^{10}	10^{-9}°K
200	20.0	100.0	0.02°K	200.0	10^{20}	10^{-19}°K

From Table II it is apparent that at a range of 10km, the frequency with the lowest value of α (i.e., αA = 0.1db/km) provides a temperature difference response of 1.6°K, while the frequency with the high value of α (i.e., αB) provides a response of only 0.9°K. At 50 km, however, the response in the high α channel is undetectable, while the channel with the low α value provides a response of 0.65°K.

Equation 12 can be rewritten in the form:

$$T_A - To/\Delta To = 1/L_1\,(1 - 1/L_2) \qquad 15$$

The right-hand side of Equation 15 is a function of the α value, the range to the CAT region, and the extent of the CAT region. The left-hand side of Equation 15 is in the form of a normalized temperature response; i.e., the numerator is the difference between the observed antenna temperature and the ambient temperature along the flight path which varies as a function of range. The denominator is the actual thermometric temperature anomaly associated with the CAT region.

Rewriting Equation 15 in prior notation form results in:

$$T_A - To/\Delta To = \Delta T_c/\Delta To \qquad 16$$

In Table II the values of ΔT_c for two assumed values of α, a temperature difference (ΔTo) of 10°K, and a CAT extent of 10 km was computed. A graphical plot of $\Delta T_c/\Delta To$ for the same condition (a step change) is shown in FIG. 2. To convert the normalized value of temperature to a measured value for ΔT_c, the vertical scale only need be multiplied by 10°K. As shown in FIG. 2, the differential temperature, at a range of 100 km for the α = 0.1 db/km channel, is 0.2°K; at 50 km, 0.65°K; and at 10 km, 1.6°K. The corresponding response for the α = 1.0 db/km channel as a function of range is negligible until the aircraft approaches to within approximately 20 km of the CAT region. At 10 km, the observed temperature difference rises sharply to 0.9°°K. FIG. 2 also includes other frequencies of observation which provide absorption coefficients of 0.2, 0.5, and 1.5 db/km for comparison purposes.

In the prior example, the temperature anomaly associated with CAT was assumed to be a step-function; i.e., an abrupt change in temperature retaining a constant value throughout the CAT region. For comparison purposes, a graphical plot, similar to FIG. 2 for a ramp temperature increase is illustrated in FIG. 3, and an exponential temperature increase is illustrated in FIG. 4. It is of interest to note that the general form of the response is essentially the same independent of the form of the temperature anomaly.

Turning now to a description of the preferred embodiment of the invention illustrated in FIG. 5, an antenna 11, which

may be a scanning type, a multibeam type or a single beam type, is connected to an orthogonal mode transducer 13, which allows the signal received by the antenna to be separated into two polarizations. One polarization is separately applied to each of a pair of channels, illustrated in FIG. 5. More specifically, the upper portion of FIG. 5 is devoted to one channel and the lower portion of FIG. 5 is devoted to the second channel. More frequencies or channels may be added if desired to provide a finer range granulation. The region between the two channels in FIG. 5 is devoted to components that are common to both channels.

Each frequency channel of the multifrequency radio-metric sensor shares the antenna 11 and comprises a RF processing section and a signal processing section. The channels also share a common output indicator system which is controlled by a common timing and reset circuit.

Each radiometric RF processing section comprises: first and second side couplers 15 and 17; a modulator 19, including its driver unit 21; an isolator 25; a mixer 27; a preamplifier 29; first and second attenuators 31 and 33; a controlled oven reference (heat sink) 35; a klystron or solid state local oscillator 37; and, first and second power supplies 39 and 41 for the klystron and the modulator driver units 21. Each signal processing section comprises: a third power supply 43; an IF amplifier 45; an envelope detector 46; an audio amplifier 47; a synchronous detector 49; an integrator 51, and a common reference generator 53. An output indicator circuit 55, a ΔT circuit 57 and a clock and reset circuit 59 are common to all frequency channels.

The signal outputs from the orthogonal mode transducer are connected to one of the inputs of the first coupler 15 of each channel. The first coupler 15 at the front of the modulator 19 allows the addition of noise from a first noise generator 61. This noise is fed to the side inputs of the first coupler 15 via the first attenuator 31. The first attenuator 31 is used to adjust the amount of added noise such that the input signal and added noise equals the input signal appearing at the reference input port of the modulator 19.

The output of the modulator 19 is connected through the isolator 25 to one input of the mixer 27. The klystron 37, which acts as a local oscillator, is tunable and connected so as to receive its input DC power from the power supply 41. The klystron is also mounted so as to apply its heat to the heat sink 35. The RF output of the klystron 37 is connected through the second attenuator 33 to the second input of the mixer 27. The output of the mixer 27 is connected through the preamplifier 29 to the input of the IF amplifier 45. The output of the IF amplifier is connected through the envelope detector 46 to the input of the audio amplifier 47. The power supply 43 is connected to the preamplifier 29, the IF amplifier 45 and the audio amplifier 47 to provide power to those amplifiers. The output from the audio amplifier 47 is connected to one input of the synchronous detector 47. The synchronous detector is switched at the same frequency as the modulator 19.

Also illustrated in FIG. 5 is a calibration section, a reference generating section, and a control section, all of which are common to both channels. The calibration section comprises: a second noise generator power supply 75 and a second noise generator exciter 73.

The reference noise generating section comprises a reference generator power supply and monitor 67, a reference control 69, and a reference temperature dual oven load 71. The output of the reference generator power supply and monitor 67 is connected through the reference control 69 to supply power to the reference temperature dual oven load 71. The dual oven load 71 is connected to inputs of the second couplers 17. The second couplers have their outputs connected to the modulators 19. The purpose of this section is to monitor the gain of each channel of the radiometric sensor so as to detect a temperature difference by subtraction of the two independent receiver channel measurements after normalization of their individual gains by the previously described procedure.

The control section comprises: a power supply 77; and, a program source 79. The power supply 77 is connected to provide power to the reference generator 53 and to the program source 79. The output of the program source is connected to the noise generator power control 75 of the second noise generating section. The reference generator 53 generates two reference signals. One reference signal is applied to the modulator and the synchronous detector of the first channel and the other reference signal is applied to the modulator and the synchronous detector of the second channel.

The output of the synchronous detector 49 of each channel is connected through the DC amplifier and integrator 51 of that channel to separator inputs of the ΔT circuit 57 forming a part of an indicator network. The indicator network also includes the clock and reset circuit 59 and the indicator 55. The clock and reset circuit 59 generates a clock signal which is applied to the ΔT circuit 57 and a reset signal that is applied to the indicator 55. The output from the ΔT circuit 57 is also applied to the indicator 55.

Turning now to a detailed description of the operation of the overall embodiment of the invention illustrated in FIG. 5, each modulator acts as a single-pole, double-throw switch. More specifically, each modulator 19 provides an amplitude modulated noise signal which is proportional to the temperature difference between the noise powers presented to the modulator's input port from the orthogonal mode transducer 13 and to the modulator's comparison port. The reference generator 53 provides the modulation control signal while the power supply 39 provides power to the modulator 19. The RF noise power with the modulated component is amplified at the RF frequency of the channel by the mixer and RF amplifier 27. The RF signal frequency of each channel is determined by the frequency of the signal generated by the klystron and preamplifier frequency. The signal frequency is further amplified by the preamplifier 29 and the IF amplifier 45. Thereafter, the signal is detected in the envelope detector 46. Finally, the envelope signal or modulated component (which is in the audio frequency range) is amplified by the audio amplifier 47.

The audio amplified signal is compared in the synchronous detector 49 with the reference generator signal. The output from the synchronous detector has a voltage level that is proportional to the input temperature difference. The output from the synchronous detector is amplified by the DC amplifier and integrator 51 in order to obtain the average value of the amplitude modulated signal. The outputs from the DC amplifier and integrators of the two channels are compared in the ΔT circuit 57 and the output from the ΔT circuit 57 is applied to the indicator to provide an indication of any temperature difference which, as heretofore described, is an indication of a CAT region.

The operation of the dual channel sensor illustrated in FIG. 5 and generally described above is based upon a modification of the absolute power measurement concept described in U.S. Pat. Application Ser. No. 686,248 for "Method and Apparatus for Providing an Absolute Power Measurement Capability," by George Haroules, et al, filed Nov. 28, 1967, now U.S. Pat. No. 3,564,420. The invention described in that patent application is a passive circuit that is connected at the input of a relative power measurement radiometer to provide an absolute power measurement capability. This invention varies the circuit described in the foregoing patent application by only introducing a first noise generator 61, a first attenuator 31, and a first coupler 15 prior to the modulator 19. The first noise generator 61 is excited by the first noise generator exciter 65 and its power supply 63. The purpose of this modification is to inject an amount of noise which when added to the input signal such that the sum appearing at the signal port of the modulator 19 balances the signal appearing at the reference port of the modulator 19. The reference port is the port coupled through the coupler to the reference noise generator 53. A functional block diagram of the RF balance circuit of the invention is illustrated in FIG. 6. This circuit is the key feature of the invention in that two or more channels are modified such that a normalized power subtraction is achieved.

With the foregoing modification, the radiometer is balanced when the antenna views the ambient temperature along the flight path. In the modified absolute mode it will measure a temperature difference ΔT_o from an ambient temperature T_o.

It should be noted that an important teaching of the invention is illustrated by the dashed lines of FIG. 5 surrounding various sub-sections of the invention. That is, the dashed lines illustrate that all of the RF components are at the same temperature. By maintaining all of the RF components at the same temperature, the summation of terms making up transmission signal path losses of prior art devices are made time invarient and hance allow the calibration and balance of the system to be independent of time.

The program 79 controls the programming of the generation of noise from the second noise generator 73 by controlling the noise generator power supply 75. The couplers couple the noise sources and the signals (either the signal from the orthogonal mode transducer 13 or the reference signal from the reference 71) to the modulator 19. The ΔT circuit 57 compares the signals representing the change in ambient temperature so that an indication of the occurrence of a CAT region can be provided to the indicator. The indicator 55 is adapted to indicate the distance from the aircraft to a temperature anomaly associated with a clear air turbulence region. The ΔT circuit 57 indicates the occurrence of distance to a clear air turbulence region by comparing the output of the radiometric channels.

The signal amplitude received from the anomalous temperature region increases as the sensor approaches the region of the phenomenon. The amount of the temperature anomaly that fills the main beam (filling factor) determines the magnitude of the received signal together with the differential temperature and range extent of the CAT region.

It will be appreciated from the foregoing description that the invention is a dual channel radiometric sensor suitable for sensing and detecting atmospheric temperature anomalies associated with clear air turbulence regions in accordance with the theory presented. It will also be appreciated that various modifications can be made within the scope of the teachings of the invention. For example, it may be desirable to have more than two channels so that simultaneous measurements at various ranges can be accommodated along the forward path of the aircraft during flight. In this manner, various distance indications of clear air turbulence regions can be provided. Consequently, alert, critical or other indicating warnings can be provided to the pilot so that he can take the appropriate evasive action to avoid CAT regions. Hence, the invention can be practiced otherwise than as specifically described herein.

What is claimed is:

1. A clear air turbulence detector comprising:

a multifrequency radiometer means having a plurality of channels for generating radiometric probes at predetermined frequencies and for generating output signals for each channel, said output signals being related to the anomalous temperature characteristics of the regions being probed;

indicating means connected to said multifrequency radiometer means for sensing the output signals from said channels and for displaying said output signals in a predetermined manner;

an antenna connected to said multifrequency radiometer means;

said multifrequency radiometer means includes two channels, each of said channels including:

a radiometer processing section connected to said antenna for processing the signals received by said channels so as to generate output signals for differential power comparison;

a signal processing section connected to said radiometric processing section for processing signals from said

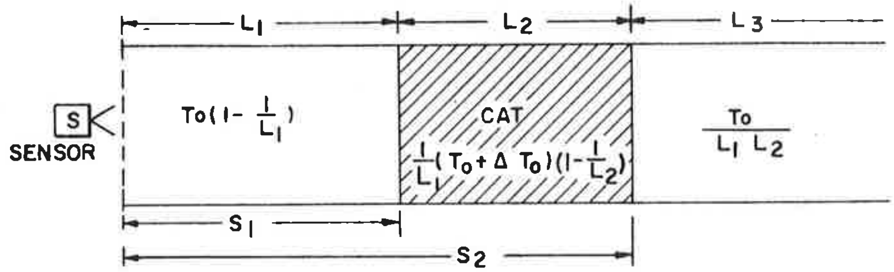


FIG.1.

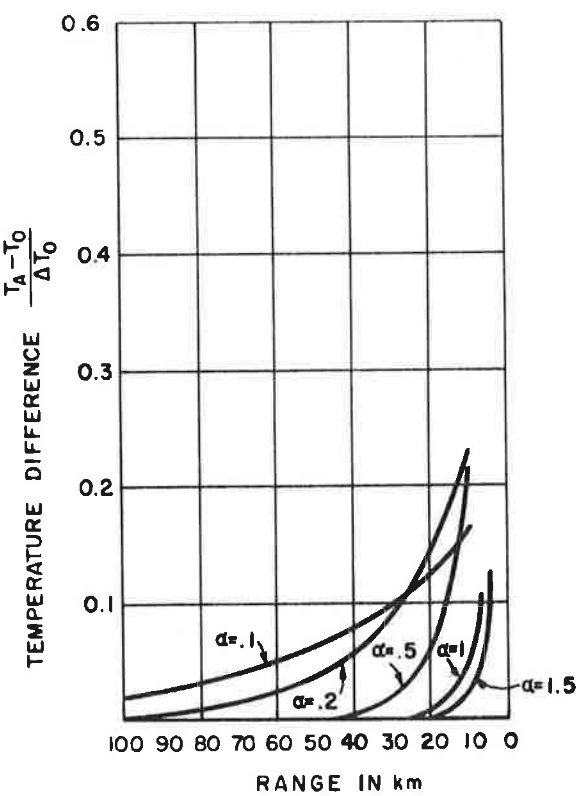


FIG.2.

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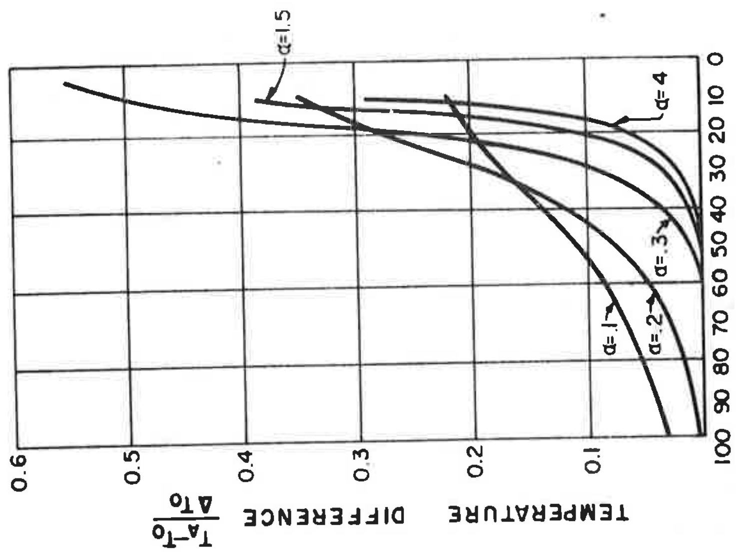

FIG. 4.

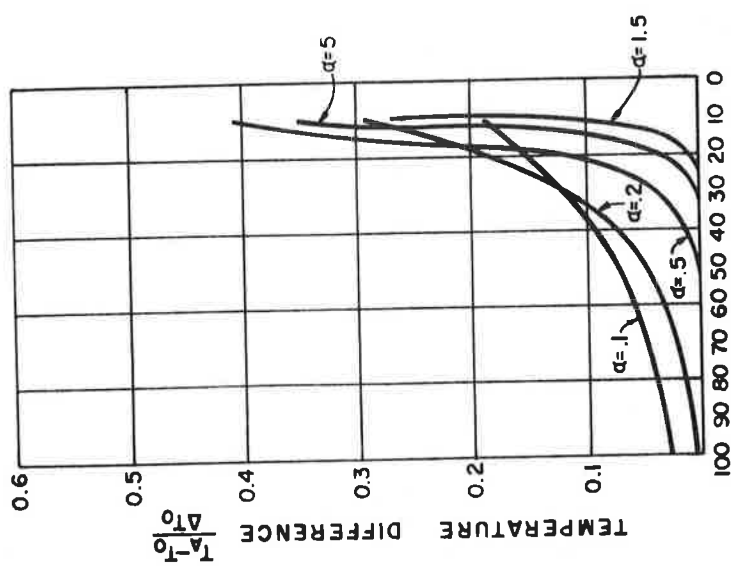

FIG. 3.

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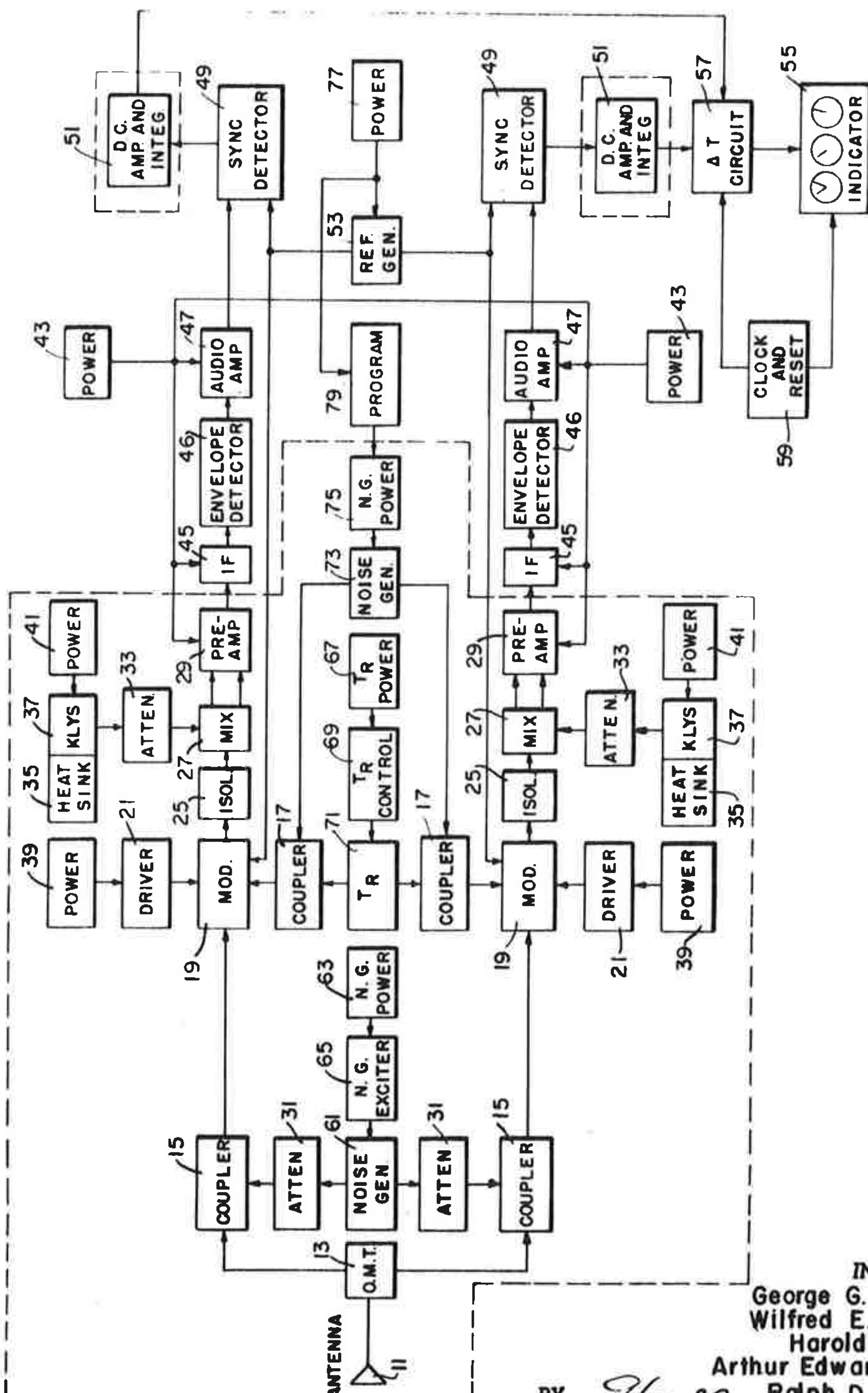

FIG. 5.

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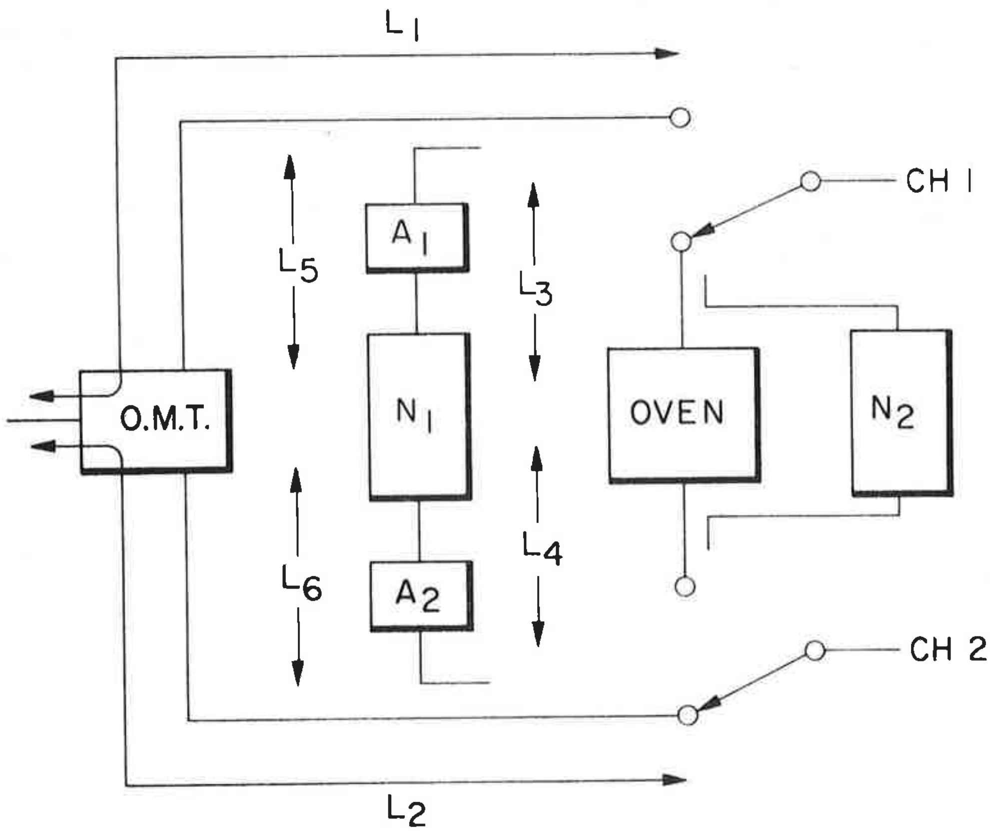

FIG. 6

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radiometric processing section and for generating a processed signal related to the range to said regions of atmospheric temperature anomalies being probed; and

an orthogonal mode transducer connected to said antenna to receive signals from said antenna and to said radiometric processing sections to apply the received signals to said radiometric processing section.

2. A clear air turbulence detector for probing the atmosphere to detect atmospheric temperature anomalies associated with clear air turbulence regions, including a plurality of radiometric channels, wherein each of said channels comprises:

an RF processing means adapted to receive RF signals related to the temperature and altitude of regions being probed;

a signal processing means connected to said RF processing means for processing the signals processed by said RF processing means so as to obtain a signal including information about the range to anomalous temperature regions along the forward flight path of high performance aircraft;

indicating means connected to said signal processing means for interpreting the signals generated by said signal processing means and for displaying information about the occurrence of clear air turbulence regions; and

a calibration means connected to said RF processing means for balancing the output of said RF processing means when a clear air turbulence region is not being probed.

3. A clear air turbulence detector as claimed in claim 2, wherein said calibration means includes a noise generator.

4. A clear air turbulence detector as claimed in claim 3, including a reference noise generating means adapted to generate a reference noise signal, said reference noise generating means being connected to said signal processing means and said RF processing means for applying a reference noise signal to said signal processing means and said RF processing means.

5. A clear air turbulence detector as claimed in claim 4, including a control means connected to said reference noise generating means for controlling the noise generated by said reference noise generating means.

6. A clear air turbulence detector as claimed in claim 5, including an antenna means connected to the inputs of said RF processing means for receiving RF signals and applying the received RF signals to said RF processing means.

7. A clear air turbulence detector as claimed in claim 6, including signal splitting means connected to said antenna means and to said RF processing means for splitting the RF signal received by said antenna means and applying said signals to said RF processing means.

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