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STRATOSPHERIC TURBULENCE AND TEMPERATURE GRADIENTS MEASURED BY AN RB-57F

Coldscan Flights 19 to 56

by
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SUMMARY

Since January 1969, a USAF RB-57F high altitude weather reconnaissance aircraft has carried a special NRC instrumentation system to measure and record stratospheric turbulence and horizontal temperature gradients encountered at altitudes from 40,000 to above 60,000 feet. The chief purpose of this co-operative program, named "Coldscan", is to collect data on atmospheric conditions at altitudes to be flown by the supersonic transports. To date, 57 data flights have been flown, covering 82,000 nautical miles of the central and western United States, Ontario, and the Pacific Ocean south of Panama. This is the second Coldscan data report and includes a summary of the results of all 57 flights, in addition to detailed accounts of a selection of 20 events from Flights 19 through 56 that showed significant temperature gradients or light to moderate turbulence. These presentations include time histories of the recorded variables, flight tracks showing event positions, and meteorological analyses. Data are presented on the correlation between measured stratospheric turbulence and horizontal temperature gradients, on the altitude and geographical distribution of the turbulence and temperature change encounters, and on the positions of the recorded incidents relative to the jet stream.

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INTRODUCTION

In January 1969, the National Aeronautical Establishment instrumented a USAF RB-57F (Fig. 1) of the 58th Weather Reconnaissance Squadron to measure turbulence and horizontal temperature gradients encountered on routine flights above 40,000 feet. The aims of this co-operative program, named Coldscan, are to collect data on atmospheric conditions at altitudes to be flown by the supersonic transports, to attempt to relate the nature and severity of each recorded incident to geographical position and meteorological conditions, and to investigate the relationship between stratospheric turbulence and strong horizontal temperature gradients.

Between January 1969 and March 1970, 57 flights covering more than 82,000 nautical miles have been flown at altitudes from 40,000 to above 63,000 feet. In Reference 1 the results of Flights 2 to 18 are reported, including detailed accounts of 15 of the more interesting encounters with turbulence and temperature gradients. Using the same format, Part 1 of this report summarizes the results of all 57 flights to date and Part 2 presents detailed descriptions of 20 significant events recorded in Flights 19 through 56. These include time histories of the recorded parameters, route maps showing the geographical positions of recorded incidents, and discussions of the meteorological conditions contributing to the events.

Data Acquisition and Analysis

The main feature of the NRC turbulence instrumentation package and memory recorder installed in the RB-57F is that it continually scans the incoming data but records only when significant parameter changes occur. A complete description of the system and its operation is given in Reference 2.

The NRC instrumentation is operated by the aircraft navigator on routine operational and training flights at altitudes above 40,000 feet. No attempt is made to deliberately encounter areas of turbulence or temperature change. To allow the navigator to perform his other duties, the instrumentation is highly automated, based on the NRC memory recorder. This 7-channel FM magnetic tape recorder has a 2-minute tape loop in addition to its 5-hour reel for permanent storage. Flight data are continuously recorded on the tape loop whenever the aircraft is above 40,000 feet and simultaneously scanned by exceedance detectors for parameter fluctuations exceeding preset levels. Whenever an exceedance is detected, the tape reels are actuated for the transfer of data from the loop to the storage tape. The two minutes of recorded data prior to the exceedance are retained, along with the exceedance, as long as it persists, plus the two minutes of data following the incident. The recorder reels can be initiated by any or all of the following exceedances:

(i) change in total temperature $\geq 2.5°C$ within a 30-second period;

(ii) vertical acceleration increment ≥ 0.35 g;

(iii) rate of change of indicated airspeed ≥ 5 knots/second.

Every stored incident is identified by a coded digital clock time superimposed on one of the recorded signals. For each exceedance the navigator logs the digital clock time, along with geographical position, altitude, aircraft weight, doppler winds, autopilot mode, and his comments concerning intensity of turbulence and local weather conditions.

Completed tapes with the navigators' data logs and maps are sent to the NAE for analysis. On tape playback, each recorded encounter is assigned a chronological flight and event number based on the coded time pulses and the information written on the data logs. Continuous time records of static (ambient) temperature are calculated by analogue computer, using the airspeed and altitude signals to correct the total temperature for the increment due to kinetic heating. This computation includes corrections to the indicated airspeed for position error and compressibility. The computed static temperature signal is recorded on 14-channel magnetic tape along with the original seven channels of data, all matched low-pass filtered with the 3 db point at 4 cycles/second. A voice channel is included on this data storage tape to record flight and event numbers as well as comments from the navigators' logs.

For each event, chart recorder traces are then prepared showing simultaneous time histories of total temperature, static temperature, indicated airspeed, normal acceleration, pitch and roll attitude, and course and fine-scale altitude. These are carefully analyzed to determine the nature of each exceedance and to select the more significant events for detailed meteorological analysis. At this stage, many events are eliminated from further serious consideration. Examples are those with g exceedances due to control inputs, or total temperature changes caused by intentional large changes in airspeed. For those events selected for detailed meteorological analysis, copies of the traces and all other data describing each event are sent to the Forecast Research Section, Research and Training Division, Canadian Meteorological Service.

PART 1

1.0 SUMMARY OF RESULTS - FLIGHTS 2 TO 56

Table 1 summarizes the flight data for the 57 Coldscan missions flown between January 31, 1969 and March 5, 1970. Data from Flights 2 to 18 are shown in totalled form since these were detailed in the equivalent Table 1 of Reference 1. Flight 11 is excluded from these totalled data since it was a special purpose lee-wave flight directed into an area of anticipated turbulence.

In the 57 project missions, 82,000 nautical miles were flown in 258 hours of flight, 199 of those above 40,000 feet. The geographical area covered in these flights is shown in Figure 2 by the superimposed ground tracks of all 57 flights, many legs of which were flown on several occasions. With the exception of three flights from Ottawa and two from Panama, all were round-trip missions operated from Kirtland AFB, New Mexico.

An "event" is defined as any activation of the permanent storage reels of the memory recorder by the automatic detection of any of the three exceedances listed above. The recorded length of an event may be as short as four minutes or, when there are continuous exceedances, the recorder will operate until two minutes after the final exceedance. The longest event recorded to date has been 19 minutes. A total of 259 events has been recorded during 57 project flights, slightly more than one for every hour of flight. During level flight, there were 54 events with static temperature change greater than 2.5°C within 30 seconds and 36 events with turbulence with at least one vertical acceleration increment greater than 0.35 g. Thirteen of these events had both the turbulence and the temperature change.

More than half of the 259 events recorded to date had neither turbulence nor the minimum 2.5°C within 30 seconds change in static temperature during level flight, and were therefore excluded from further analysis. Most of these events were g exceedances caused by pilot or autopilot control inputs; many were temperature change exceedances during climbs and descents near the tropopause; and several were total temperature changes caused solely by substantial changes in airspeed.

1.1 Duration of Turbulence

In 57 Coldscan missions to date, a total of 86 minutes of turbulence was encountered during cruise at altitudes above 40,000 feet. This figure excludes Flight 11 data since it was directed into an area of suspected lee-wave activity. The duration of turbulence for each encounter was defined as the period during which there were continuous excursions of the accelerometer trace with at least one spike exceeding 0.35 g. For the RB-57F, this level of acceleration corresponds to a derived gust velocity (Ref. 3) of about 8 feet/second.

The 86 minutes of turbulence encountered on these routine undirected flights represent 0.72% of the 199 hours flown above 40,000 feet. The comparative figure given in Reference 1 for the first 18 flights of the program was 1.2%. The lower figure of 0.72% is a better representation of a yearly average, since the smooth flights of July-October 1969 are reflected in the results. The percentage of time in turbulence quoted for these data is lower than previous U-2 experience, primarily because of the higher threshold of vertical acceleration used to define turbulence in this study.

1.2 Geographical Distribution of Events

Of the 82,000 nautical miles flown in 57 flights to date, 45% were flown over or within 30 nautical miles of mountainous terrain. In comparison, of the number of events with known geographical positions, 74% of those with turbulence and 77% of those with the 2.5°C in 30 seconds temperature gradient were over or within 30 nautical miles of mountains. Furthermore, turbulence and temperature gradients encountered away from mountains were generally milder than for the events near mountainous terrain. The detailed accounts in Part 2 of this report, and Reference 1, show that many of the more significant events recorded during winter and spring flights were the result of mountain waves.

1.3 Altitude Distribution of Events

The amount of turbulence (or number of temperature changes) encountered in a given altitude band obviously depends upon the amount that naturally occurs in the particular band as well as the time flown within the band. Figure 3 graphically depicts the distribution by altitude band of the hours flown, the time in turbulence, and the number of events with temperature change greater than 2.5°C within 30 seconds. To make the three plots easily comparable, the abscissa in each case represents the percentage encountered in each altitude band of the total experienced above 40,000 feet. For example, 57% of the hours in cruise above 40,000 feet were flown in the 5,000-foot band centered at 50,000 feet, with another 21% between 57,500 and 62,500 feet.

Comparison of Figures 3a and 3b indicates a possible increase in the occurrence of turbulence in the 50,000 and 55,000-foot altitude bands and a decrease at the higher altitudes (i.e. 67% of the total amount of turbulence was experienced near 50,000 feet where only 57% of the cruise hours were spent). For the incidents with temperature change, the opposite appears to be true. There is an increase in the frequency of occurrence in the 55,000-foot band and above and a decrease at 50,000 feet and below.

These trends become more evident in Figure 4, where the same data are presented normalized with respect to the time flown in each altitude band. Figure 4a clearly shows the increase in the occurrence of turbulence in the 50,000 and 55,000-foot altitude bands, an observation that was also noted in the U-2 HICAT data (Ref. 4). The curve is shown as a dashed line below 47,500 feet because no turbulence was encountered at these levels owing to the small number of hours flown there.

In Figure 4b, the altitude distribution of events with temperature changes of two magnitudes has been plotted as the number of encounters per 1,000 nautical miles. The solid curve represents changes greater than 2.5°C within 30 seconds and has an average of 0.8 encounters per 1,000 nautical miles above 40,000 feet. As discussed above, there is an above-average frequency of occurrence in the 55,000-foot altitude band and above, and below average at 50,000 feet and below. The larger temperature changes, greater than 5°C during the event, appear to be more uniformly distributed about an average of one encounter every 2,000 nautical miles.

1.4 Horizontal Temperature Gradients

Figure 5 shows the changes in the static (ambient) temperature encountered in Flights 2 to 56 versus the distance over which the changes took place. Most of the larger rates of change of temperature shown in this Figure are from events discussed in detail in Part 2 of this report and Reference 1. Many of these large temperature gradients were concluded to be associated with mountain waves. A few events are represented by more than one point in Figure 5, since each half-cycle of a wave in the temperature trace contributed a point to the plot.

The maximum rate of change of temperature encountered to date in a routine undirected Coldscan mission was 5°C in 2/3 of a nautical mile at 63,000 feet (Flight 3, Event 1 - Ref. 1). However, temperature changes considerably greater than this have been measured recently by this system when the aircraft participated in the 1970 Colorado Lee Wave Experiment organized by the National Centre for Atmospheric Research at Boulder, Colorado. Some of the temperature changes measured over the Rocky Mountains by the RB-57F were 8°C in 0.23 nautical miles at 62,000 feet, 20°C in 7 nautical miles at 57,000 feet, and 6°C in 0.06 nautical miles at 53,000 feet. These and other incidents will be reported more fully in the results of the 1970 Colorado Lee Wave Experiment. .

1.5 Correlation Between Turbulence and Temperature Gradients

An important objective of Project Coldscan is to collect data on the possible correlation between turbulence and horizontal temperature gradients in the stratosphere. The results of this analysis for 57 flights covering 82,000 nautical miles are shown in Figures 6 and 7. In the interpretation of these results, the threshold levels used in the Coldscan instrumentation must be kept in mind, for the aims of the project are primarily to investigate turbulence and temperature gradients of a magnitude that may affect SST operations. The minimum rate of temperature change to activate the recorder, for example, represents a gradient of almost 3/4°C per nautical mile.

On the left of Figure 6 is shown the percentage of all turbulence events that also had temperature exceedances somewhere during the event. Slightly more than one-third of the turbulent events also contained a temperature change greater than 2.5°C in 30 seconds, and one-quarter recorded a temperature change in excess of 5°C in one minute (or 6-1/2 nautical miles).

The reverse correlation, that is the percentage of events with temperature change exceedances that also included turbulence, is illustrated on the right side of Figure 6. Three temperature change categories were analyzed. For the 54 events with the minimum temperature change to actuate the recorder, only 24% also contained turbulence of sufficient intensity to have at least one vertical acceleration increment greater than 0.35 g. Thirty of these 54 events had a temperature change of at least 5°C during the event, and 30% of these had turbulence. Furthermore, in 23 of these 30 events, the temperature changed the 5° within one minute. Thirty-nine percent of the events in this group recorded turbulence. It can be concluded from these results that the larger temperature changes are more often associated with turbulence, although the probability of a 0.35 g turbulence encounter accompanying a temperature change of even 5°C in 6-1/2 nautical miles is still less than 40%.

Figure 7 is another illustration of the correlation between the measured stratospheric turbulence and temperature gradients. The hatched circle on the left represents the 36 events with turbulence of at least 0.35 g peak intensity, while the larger hatched circle on the right depicts the 54 events with the 2.5°C in 30 seconds temperature change. The lens-shaped overlap of the two circles represents the 13 events belonging to both sets, and shows that the stratospheric 0.35 g turbulence and temperature gradients are not well correlated.

Twelve of the 36 turbulence events were reported to be of moderate intensity or greater, with vertical acceleration increments exceeding 0.5 g. These are shown in Figure 7 as the unshaded circular subset of the 0.35 g turbulence circle. A greater percentage of these events (67%) also contained a temperature change exceedance, indicating that the correlation between the stratospheric turbulence and temperature gradients improves with the intensity of the turbulence, as well as with the magnitude of the temperature change.

1.6 Jet Stream

A statistical analysis was carried out to determine the distribution of the events about the jet stream. The distance between the closest tropospheric jet stream and the position of each of the events was calculated using 300-mb analyses prepared by the Canadian Meteorological Service. The 300-mb position of the jet stream was selected because it was most easily available. When the jet stream is at a higher level, the 300-mb jet position is usually slightly south of the actual maximum. This will result in a slight shift of the maximum of the distribution to the north. Seventy-four of the events encountered thus far have geographical position information, and these were used for this analysis. Interpolation between jet stream positions was used for those cases when the event occurred between the analysis times of 00.00 and 12.00 hr GMT. In addition to an overall distribution, the nature of the underlying terrain was also noted so that a comparison could be made between mountainous and non-mountainous terrain. The results of this analysis are shown in Figure 8.

Most of the events occurred within 240 miles of the jet stream, and 45% within 120 miles and over the mountains. The combination of high tropospheric winds and mountains frequently results in large amplitude lee waves. This is especially true in the western United States where the jet streams are frequently oriented normal to the north-south mountain ranges. It is worth noting here that 54 out of the total of 77 events were caused by temperature changes, and these were usually associated with mountain waves.

The results also indicate that 65% of the events occurred south of the jet stream. As mentioned above, the use of 300-mb jet stream position would have a tendency to increase the apparent number of events encountered north of the jet, so that this percentage could be a slight underestimate. However, six of these events occurred more than 480 miles south of the jet and should not be included. Even so, 62% of the remaining events occurred south of the jet.

It was thus necessary to establish what percentage of the total flight mileage was made south of the jet. To do this the flight tracks of 53 flights were plotted on the 300-mb charts. The flight distances flown were then divided into sectors dependent on the distances from the nearest jet stream. The results of this analysis are shown in

Figure 9. In order to remove the effects of noise and a small sample, the data were smoothed using a 6-degree-of-latitude base triangular weighting function. The mean flight position was 0.03° north of the jet while the median was 0.1° north.

The distribution of the events was also smoothed with the triangular weighting function and the two smoothed distributions were used to compute a distribution of the number of events per 10,000 miles for each 2° band. The resulting distribution is shown in Figure 10. The smoothed distributions were used because there were too few data to give meaningful ratios from the raw data.

The results indicate that it is more likely that an event will be encountered south of a jet stream, with the median value of this distribution being 2.8° south of the jet. However, most of the events occurred in the vicinity of mountains. It appears that the majority of these events resulted from the high winds near the jet blowing over mountains to set up lee waves, rather than being directly related to the jet stream position alone. South of the jet the associated frontal surface is usually at or near the ground. Above this surface there is usually little or no thermal wind, that is, the wind direction does not vary greatly with height. The maximum in the event frequency just south of the jet probably occurred at this distance because the associated frontal surface was generally below the mountain tops while the jet stream was sufficiently close to ensure strong winds at most levels.

1.7 Future Coldscan Missions

The Coldscan measurement program will continue to record turbulence and temperature gradient encounters on RB-57F routine operational and training flights out of Albuquerque, New Mexico. However, larger geographical coverage is anticipated during the winter of 1970-71, with more operations out of Panama and off the west coast of South America. To provide more information in other regions of interest from the standpoint of supersonic transport operation, it is hoped that it will be possible to arrange for flights off the Eastern seaboard of the United States and Canada and north of the Arctic Circle.

TABLE 1

COLDSCAN FLIGHT AND EVENT SUMMARY - FLIGHTS 2 TO 56

Flight	Date 1969-70	Cruise Alt. × 1000 ft	Flight Hours		Nautical Miles	Total Number of Events	Number of Events During Cruise			Duration of Turbulence min
			Total	Above 40,000 ft			With Static Temp. Change ≥ 2.5°C in 30 sec	With Turbulence	With Both Temp. Change and Turbulence	
Total Flts. 2 to 18 Excl. Flt. 11	Jan. 31 to Jul. 9		82.4	70.2	28470	72	17	19	8	47.3
19	Jul. 23	50	6.68	5.95	2420	5	1			
20	29	58	.78	.68	260	2				
21	Sept. 8	35 - 47	3.10	1.82	950	4				
22	9	35 - 50	2.37	.91	520	5				
23	10	50	4.38	3.91*	1580	6				
24	17	60	4.05*	3.47	1470	4	1			
25	Oct. 1	50	4.95	4.42	1820	3				
25A	2	50	5.05	4.35	1860	1				
26	3	50	5.05	4.37	1820	7	1	2	1	1.7
27	13	59	6.06	5.48*	2300	4	1			
28	Dec. 9	50	6.42*	5.67	2330	18	4	2		4.6
29	10	49	6.33	5.48	2000	10		1		1.9
30	11	50	6.23	5.61	2330	7	3			
31	12	49	3.87	3.42	1400	6	4	1	1	3.8
32	15	50	3.70	2.65	1110	2		1		2.2
33	22	50	5.55*	4.88	2050	7	1	3		6.1
34	Jan. 13	60 - 62	5.35	4.60	1950*	7	1			
35	Feb. 2	50	3.97	3.53	1590	8	1	2	1	1.8
36	3	59	4.07	3.55	1540	4	2			
37	4	50	2.05	2.05	755	3		1		4.8
38	5	50	6.55	5.90	2475	2				
39	6	60	5.80	5.08	2160	4				
40	9	50	6.00	5.32	2160	5				
41	11	59	4.00*	3.34	1470	4				
42	12	60	4.20	3.53	1510	7	3			
43	13	50	2.06	1.43	630	2	1			
44	14	45	1.15	.50	370	2				
45	17	45	2.27	1.45	630	4	1			
46	18	51	2.32	1.50	630	2	1	1	1	3.8
47	20	50	4.04*	3.37	1300	6	1	1	1	.6
48	24	55 - 60	1.03	.55	280	2				
49	25	61 - 63	4.82	4.22	1810	3		1		1.6
50	26	43 & 50	2.28	1.80	630	3	1			
51	27	50	3.72	2.85	1180	11	3			
52	Mar. 1	43 & 63	1.45	.96	370	3				
53	2	50	5.50	3.80	1540	6	3	1		5.4
54	3	43 & 50	2.18	1.69	630	3	2			
55	4	60	2.32	1.42	630	2	1			
56	5	41 & 50	4.28*	3.52	1300	3				
57 Flts.			238.4	199.2	82230	259	54	36	13	86

* Estimated

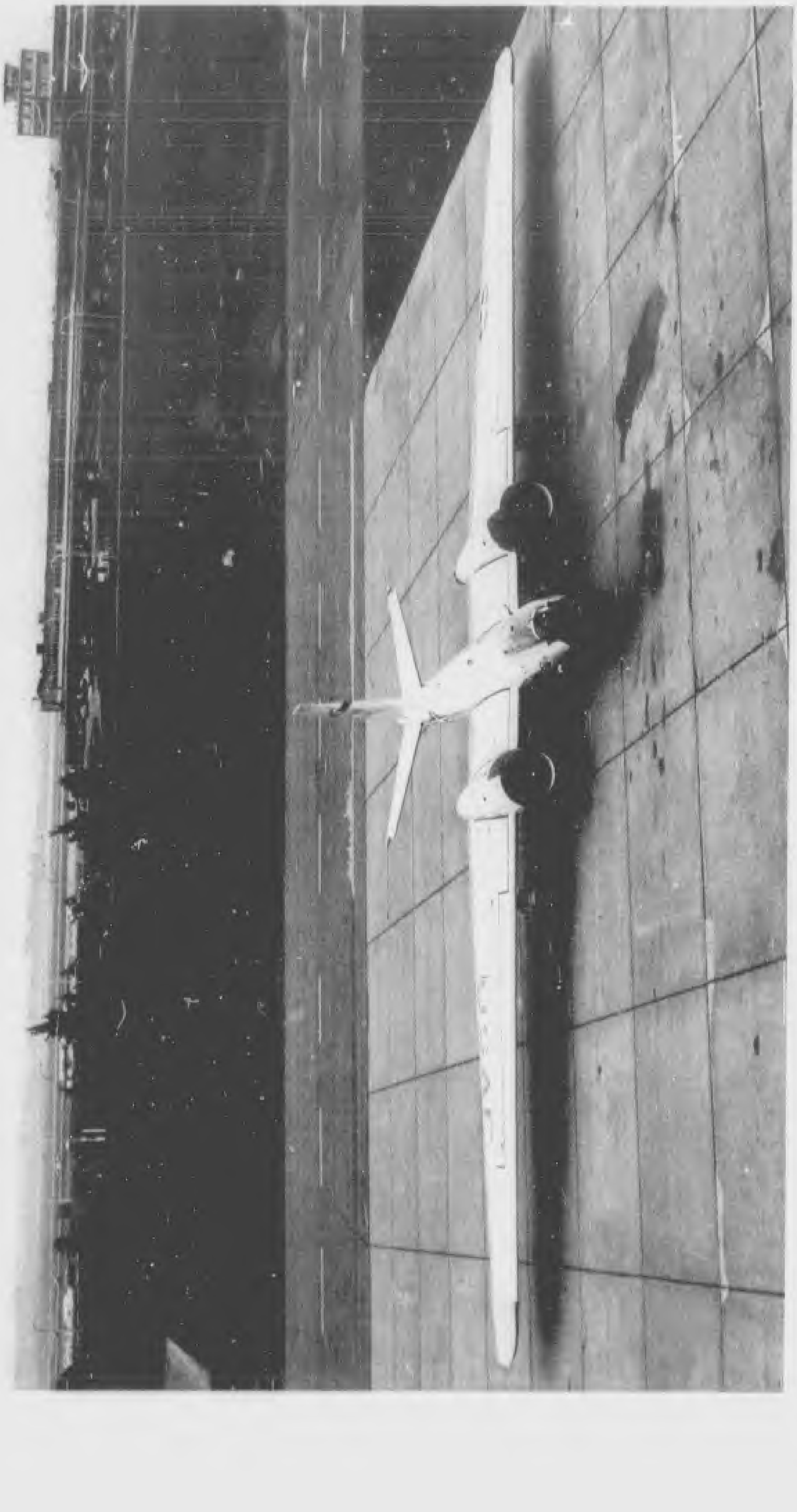

FIG.1: THE RB—57 F

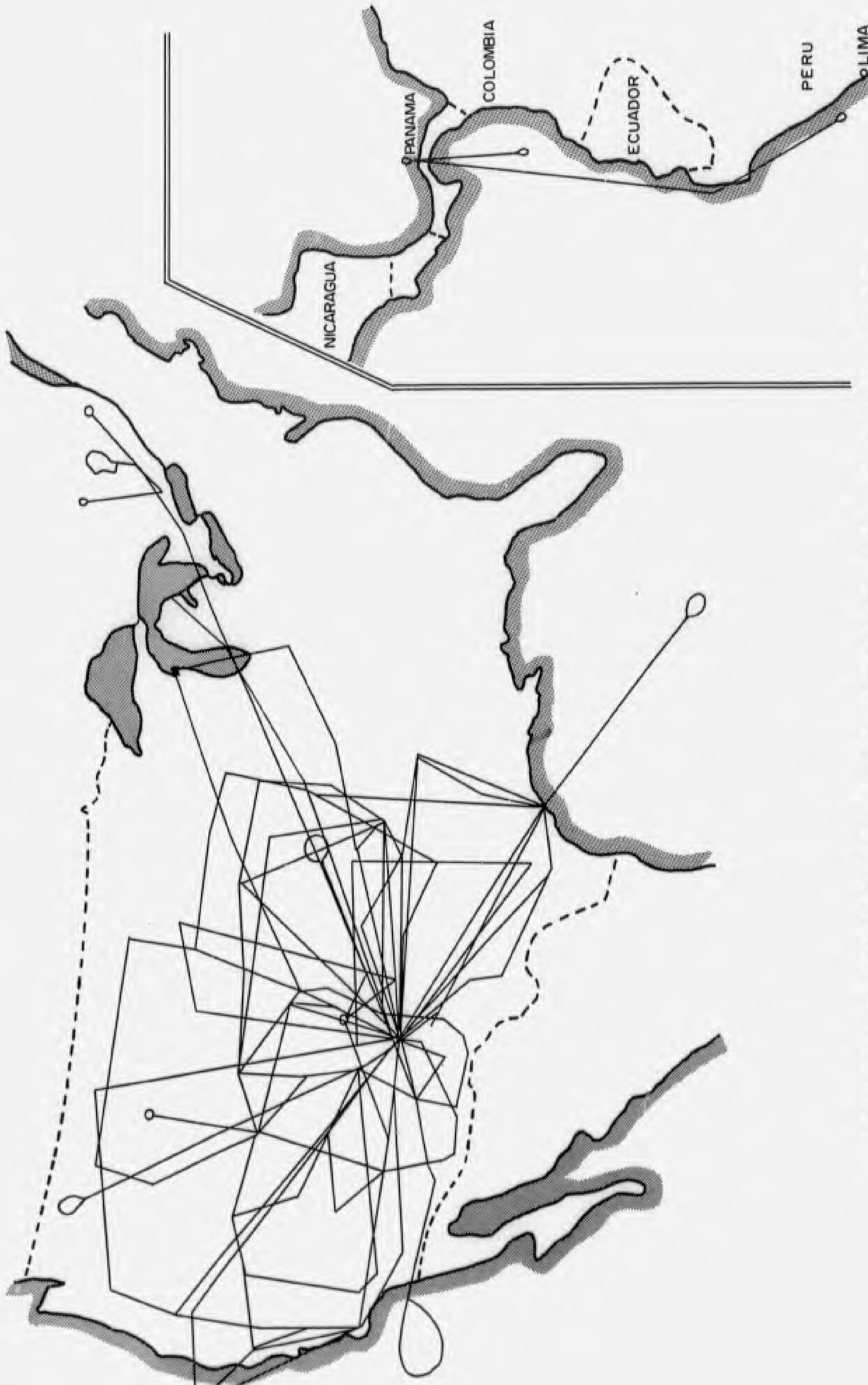

FIG. 2: GEOGRAPHICAL AREAS OF COLDSCAN FLIGHTS 2 TO 56
31 JAN 1969 – 5 MAR 1970

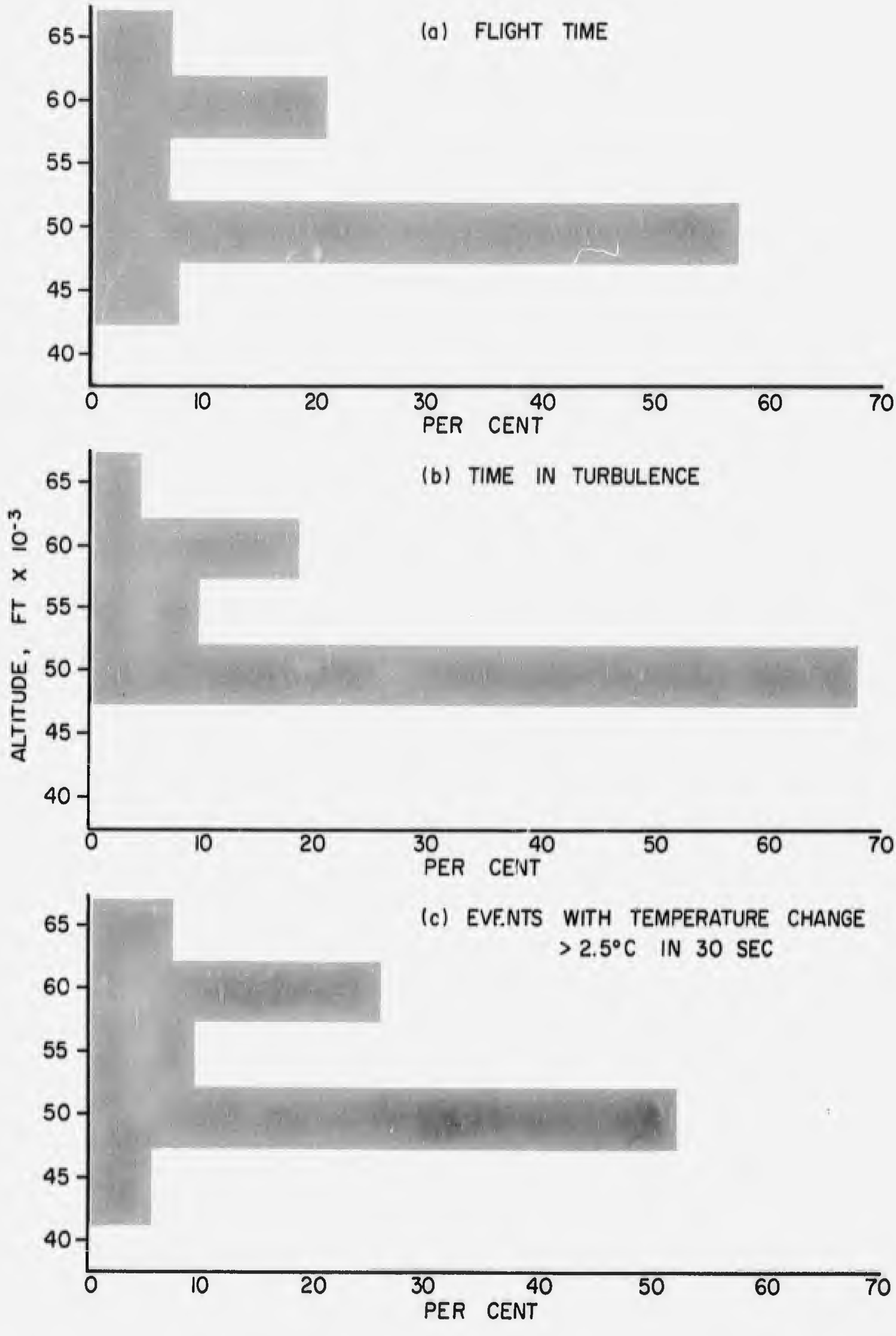

FIG. 3: PERCENTAGE DISTRIBUTION BY ALTITUDE BAND OF FLIGHT HOURS, TIME IN TURBULENCE, AND TEMPERATURE CHANGE EVENTS

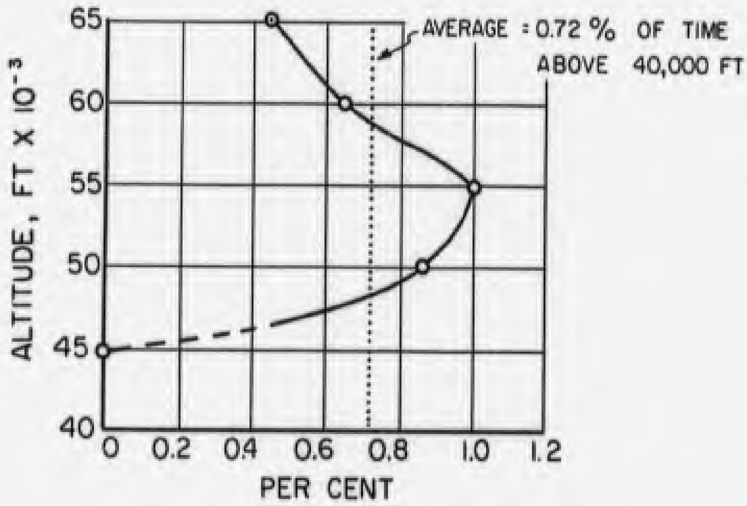

FIG.4a: VARIATION IN PERCENTAGE OF TIME IN TURBULENCE WITH ALTITUDE

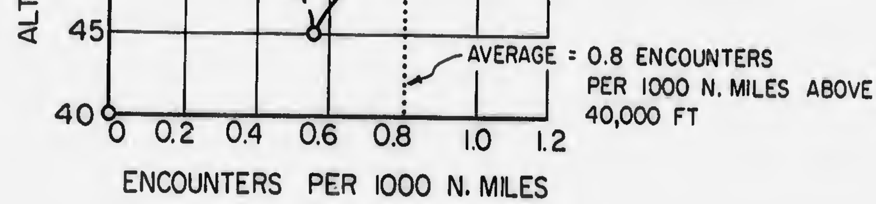

FIG.4b: FREQUENCY OF OCCURRENCE OF TEMPERATURE CHANGES

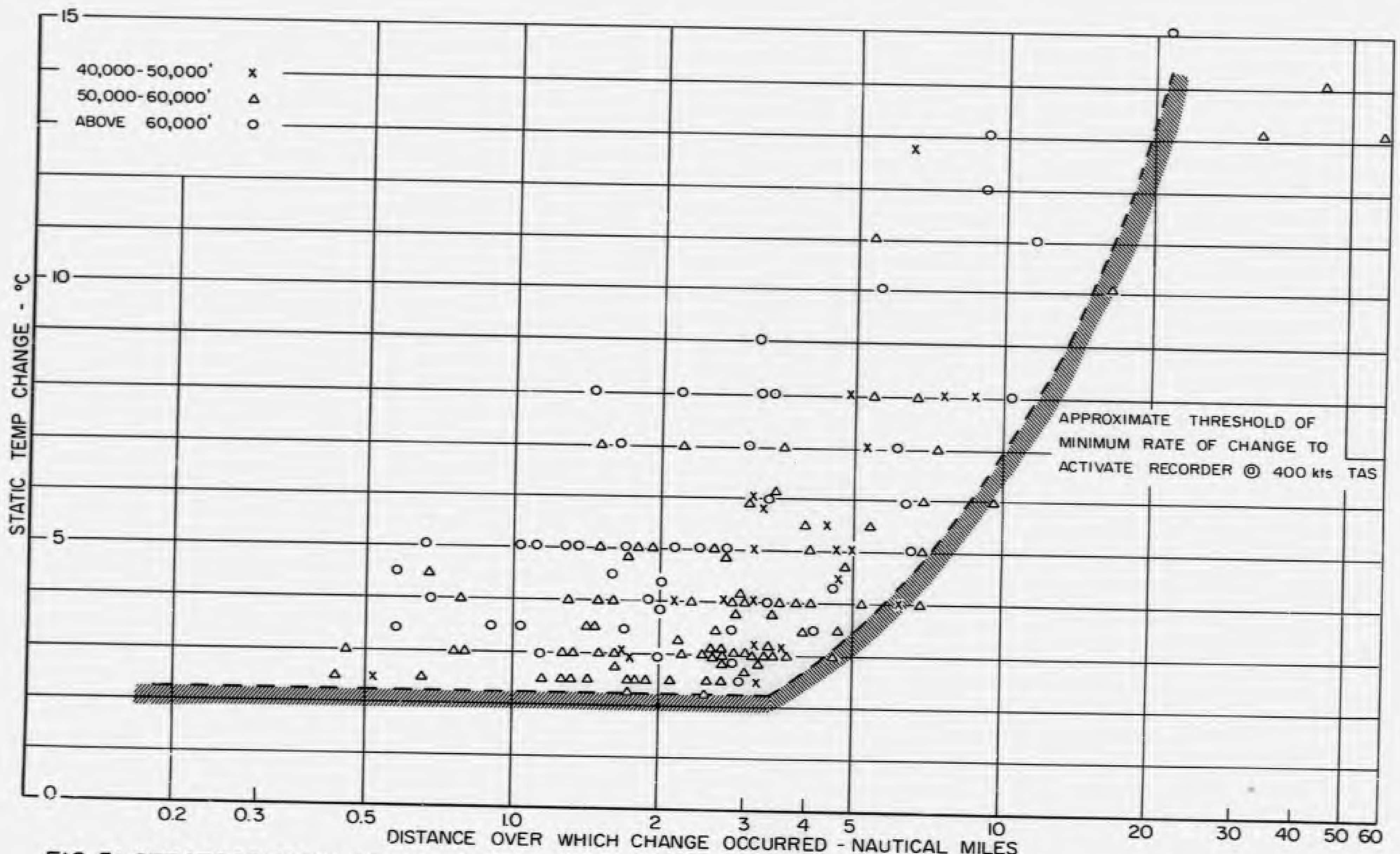

FIG. 5: STRATOSPHERIC TEMPERATURE CHANGES—COLDSCAN FLIGHTS 2 TO 56 — JAN 69 TO MAR 70

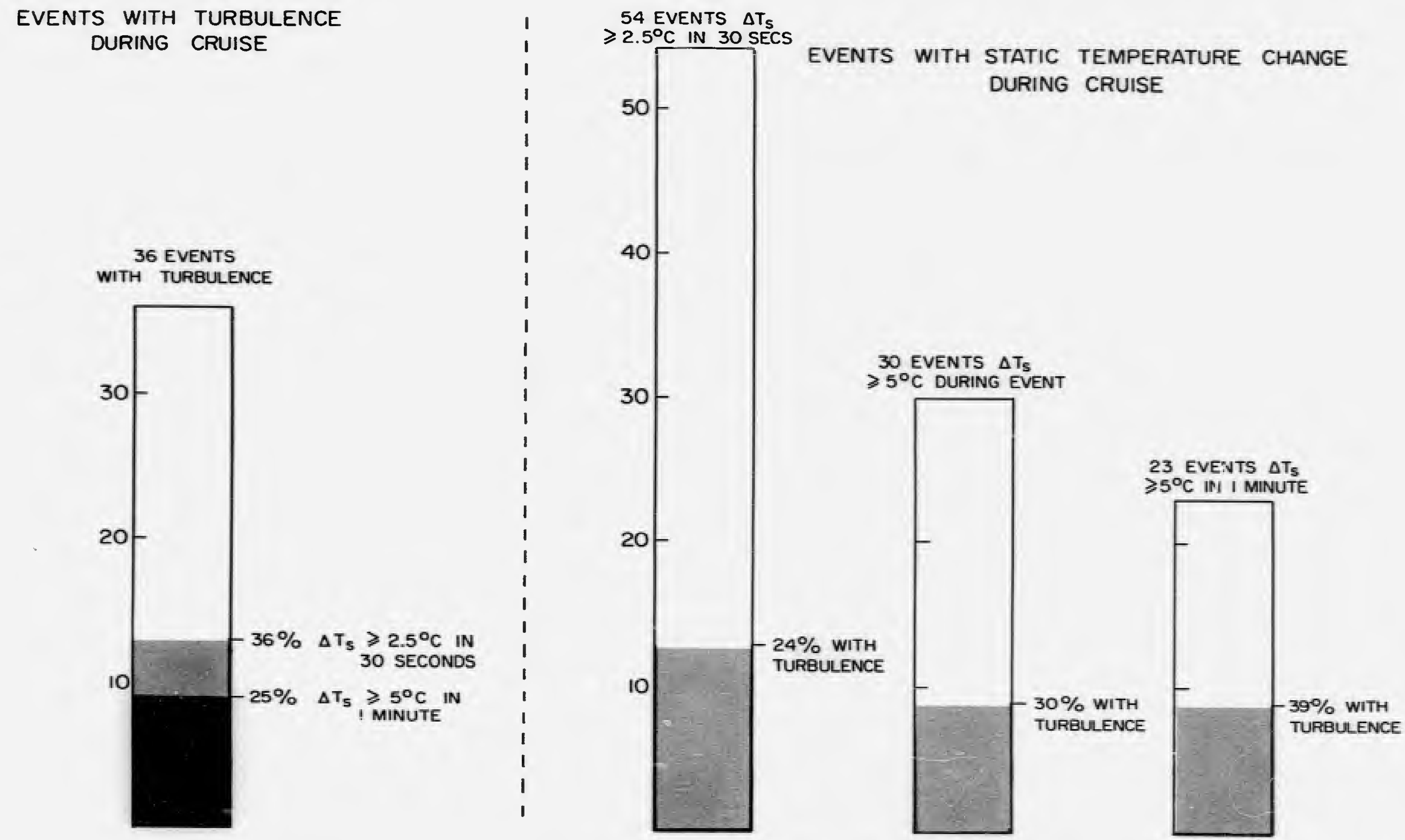

FIG. 6: CORRELATION BETWEEN TURBULENCE AND TEMPERATURE CHANGE ABOVE 40,000 FEET FLIGHTS 2 TO 56

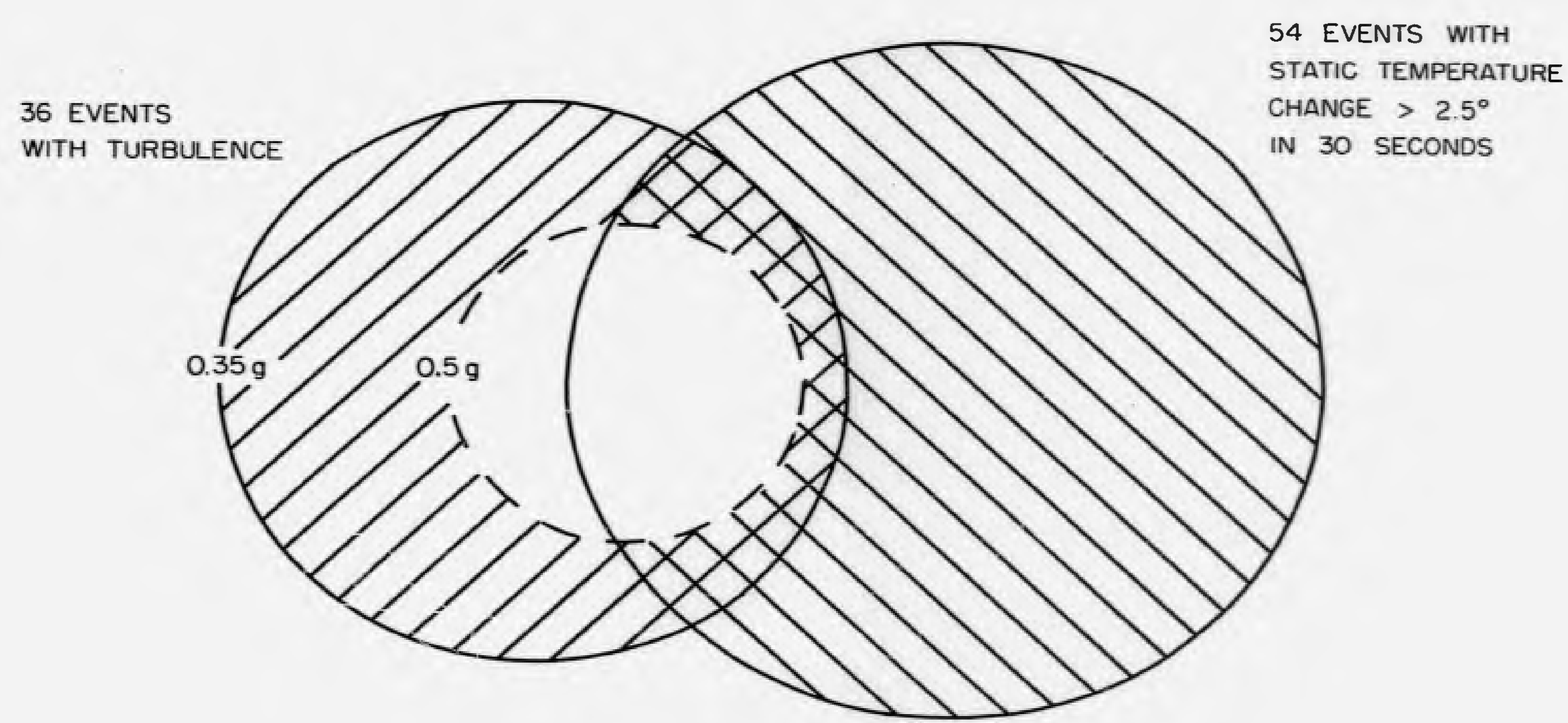

FIG. 7: CORRELATION BETWEEN TURBULENCE AND TEMPERATURE CHANGE ABOVE 40,000 FEET FROM 82,000 NAUTICAL MILES OF FLIGHT

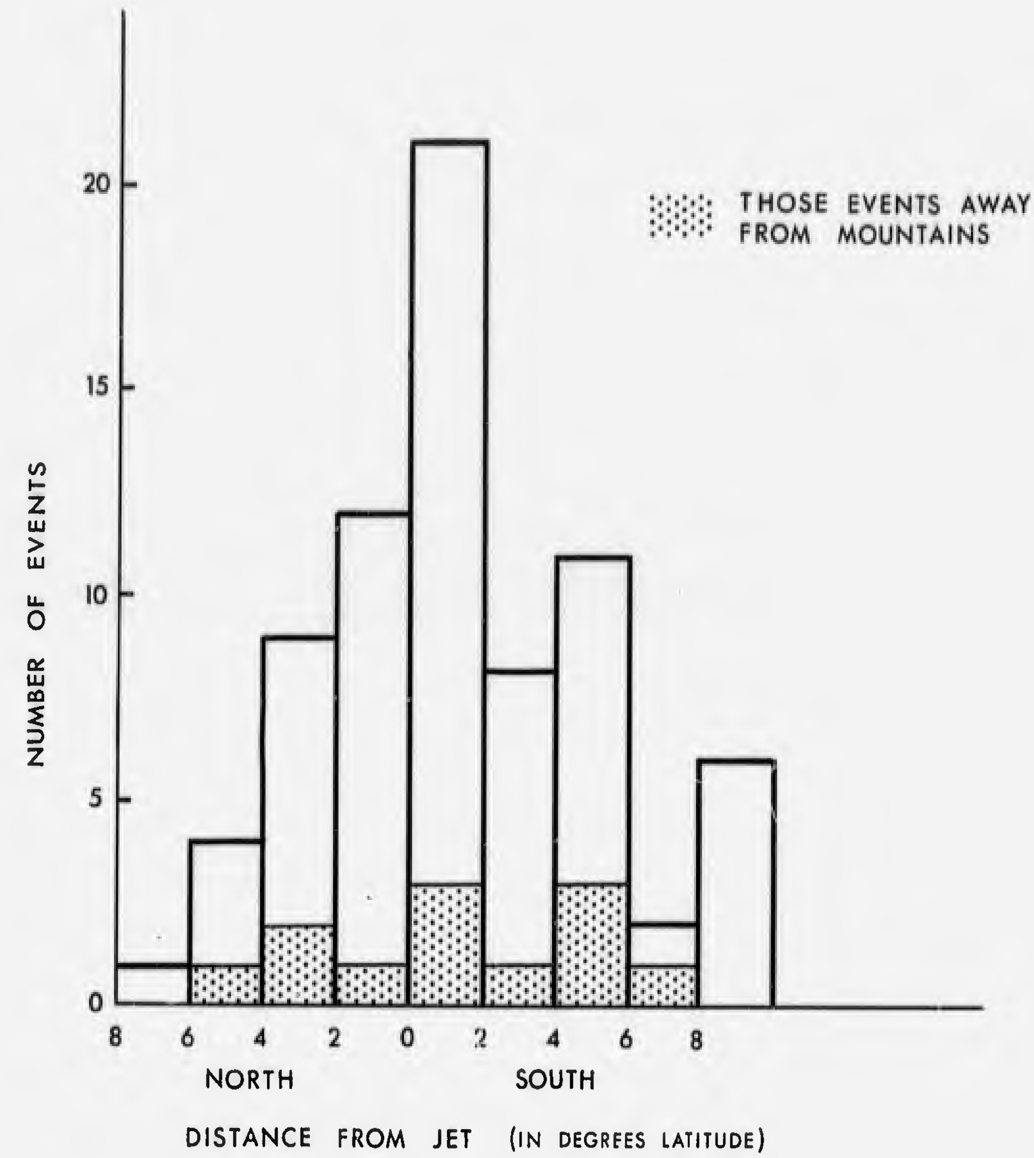

FIG. 8: DISTRIBUTION OF EVENTS ABOUT THE JET STREAM

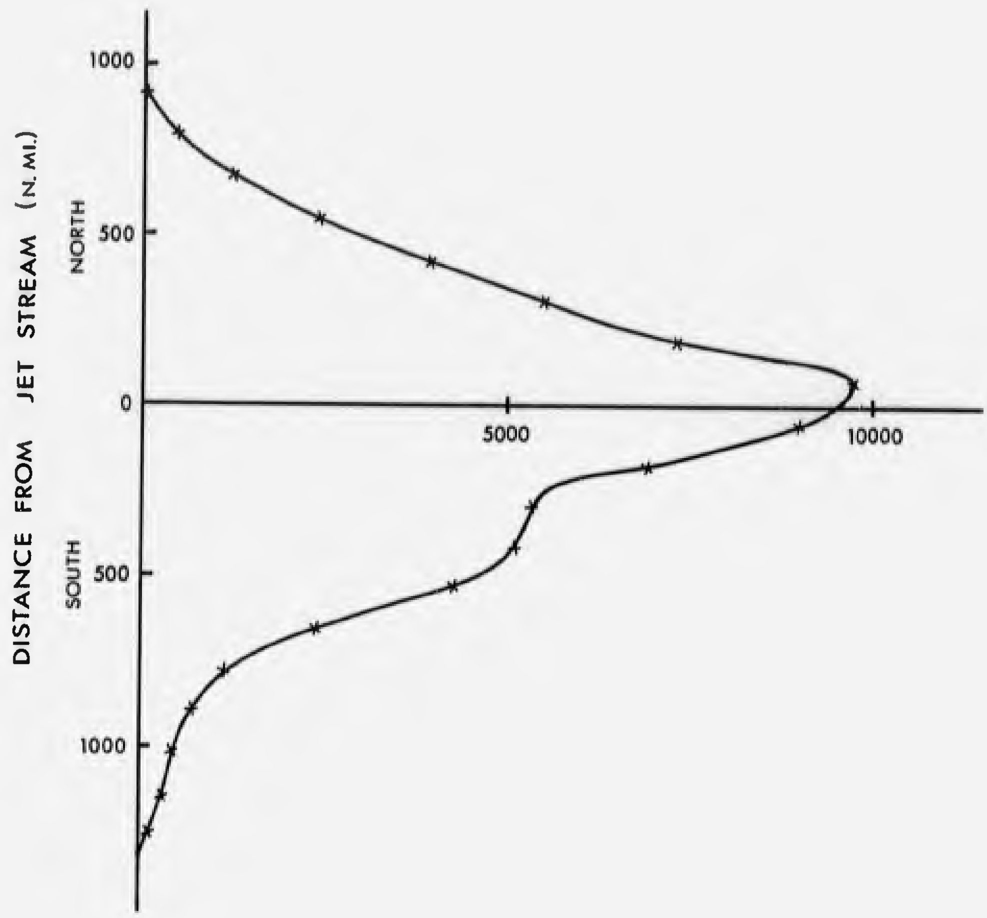

FIG.9: DISTRIBUTION OF FLIGHT MILEAGE ABOUT THE 300-MB JET STREAM POSITION

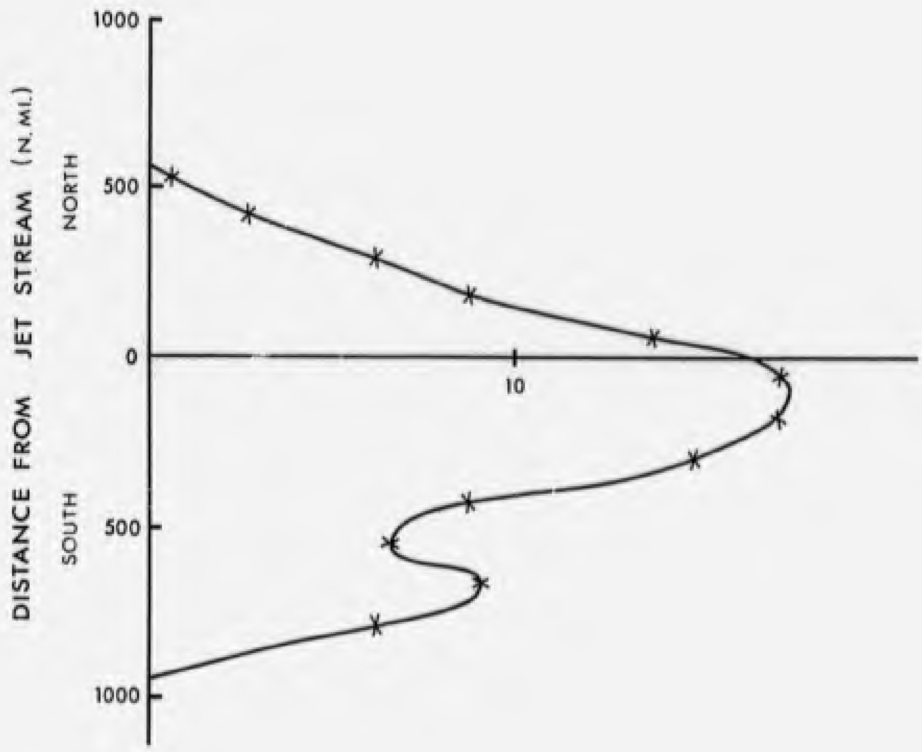

FIG 10: FREQUENCY OF EVENTS (PER 10,000 N. Mi.) AS A FUNCTION OF DISTANCE FROM THE 300-MB JET STREAM POSITION

PART 2

2.0 SPECIAL EVENTS

Of the 259 events recorded to date in Project Coldscan, 15 were selected from Flights 2 to 18 for a more detailed presentation in Reference 1, and a further 20 from Flights 19 through 56 are analyzed in a similar manner below. The events chosen for detailed presentation are those with the most significant turbulence and horizontal temperature gradients. Data are presented in 11 sections, one for each of the 11 flights from which the 20 events were selected. Each section contains a discussion of the flight data and meteorological conditions, time histories of the measured parameters for each event, route maps showing event positions, and plotted and tabulated meteorological data.

The lengths of the events discussed below vary from the minimum 4 minutes to as long as 14 minutes. To present maximum detail, time histories are therefore presented with scales that change from event to event, especially along the time axis. Each spike on the time scale shown below the vertical acceleration trace represents 5 seconds. Roll attitude is shown only when it is varying significantly. Calibration pulses occurring simultaneously on all channels are identified by "CAL" written on the altitude trace, and digital clock pulses and event marks are labelled when they appear on the roll attitude trace. On some of the flight data, 5 to 7 seconds of noise occurs simultaneously on all traces at 2-minute intervals. This was the result of a poor splice in the tape loops on the memory recorder. This noise is most evident on the traces of Flights 28 and 30.

The continuous time records of static temperature were calculated by analogue computer from the total temperature, altitude, and indicated airspeed signals (corrected for position error) using the recovery factor of 1.0 for the total temperature probe. Because the response rates of the total temperature and airspeed systems differ, high frequency fluctuations (greater than 0.5 cycles/sec) appearing on the static temperature trace during turbulence should not be considered real.

Maps accompanying each of the described incidents show the flight track as a dotted line becoming a solid black line at the position of the event. The event commences at the crossbar and ends at the arrowhead. Map scales are indicated by the 60 nautical mile spacing of the latitudes.

Each flight analyzed in this way has a table of parameters following the description of the events. The derivation of these parameters is as follows.

1. Flight Level. This is obtained from the recorded altitude trace and represents an average flight level during the event. Units are feet.
2. Terrain. This is a description of the underlying terrain in general terms (mountains, hills, plain, ocean, etc). Abbreviations are used but have obvious meanings.
3. Wavelength. The wavelength is computed from the static temperature trace and the ground speed. The component of the wavelength along the wind direction is computed and it is this value that is presented in the table. Usually an average of several waves is used unless the differences are very great, when individual values will be entered. Units are nautical miles.

4. Amplitude. This is obtained from the static temperature trace and represents half of the difference between the highest and lowest temperatures recorded during the event. Units are degrees Celcius.

5. Vertical Velocity. This is the vertical wind velocity that a sinusoidal lee wave with the wavelength and amplitude computed above would have in an isothermal atmosphere. The wind speed used in this computation is usually taken from the navigation log or the closest rawinsonde ascent. The derivation of this parameter is detailed in Reference 1. The units are feet per second.

6. Distance from the Jet. This is the horizontal distance between the position of the event and the 300-mb jet stream. The 300-mb analyses used were prepared by the Central Analysis Office of the Canadian Meteorological Service. Interpolation in turn is used when either the event occurred near 0600 or 1800Z or when the jet stream appeared to have moved rapidly. Units are nautical miles and the position of the event (north or south of the jet) is also noted.

7. Jet Max. This is the maximum speed of the jet as shown on the 300-mb analyses. Corrections and interpolation were carried out in a manner similar to that used in Paragraph 6 above. Units are knots.

8. Wind Speed. This is the wind speed at flight level obtained from the navigator's log as computed from the measured true airspeed and doppler ground speed and drift. The units are knots.

9. Turbulence. This is approximately the peak vertical acceleration recorded for the event after the subjective removal of the portion of the acceleration that was due to high pitch rates. Units are in g's.

10. Time Difference. This is the number of hours between the event and the closest meteorological data set. Negative values denote the event occurred prior to the meteorological measurements.

2.1 Flight 26, 3 Oct. 1969 - Event 6 (Fig. 11 to 13)

Event 6 of Flight 26 occurred at 50,000 feet just prior to descent into Albuquerque while the aircraft was being flown with the autopilot off. Both vertical acceleration and temperature exceedances were detected as the aircraft encountered 1.7 minutes of light to moderate turbulence accompanied by a rising total temperature (Fig. 11). This was followed by waves in the static temperature trace with the rate of temperature change reaching -7°C in 13 seconds (1.3 n. miles) at one point.

The area of the event was in a strong southwesterly flow at all levels below 56,000 feet. This flow resulted from a deep trough over the western United States. A strong jet stream, imbedded in the trough, had a maximum just northeast of Las Vegas, Nevada, with northwesterly winds of 130 knots at the 300-mb level. The Albuquerque rawinsonde data are shown in Figure 13.

The event occurred to the lee of the Manzano Mountains just southeast of Albuquerque (Fig. 12). The length of the waves appeared to shorten as the aircraft approached the crest of the range. The wavelength was estimated using the doppler winds reported by the navigator, which were more westerly (about 270° true) than those measured by the rawinsonde 4 hours later. Well-formed waves have been reported to the lee of those mountains on several of the Coldscan flights out of Albuquerque.

The turbulence was encountered downstream of the trough of the longest wave encountered. This was the wave farthest from the mountains that had a temperature change of sufficient amplitude to trigger the event recorder.

Event Data

Event number	6
Flight level (ft)	50,000
Terrain	Mountains
Wavelength (n. mi)	8-10
Amplitude (°C)	5
Vertical velocity (ft/sec)	15-20
Distance from jet (n. mi)	180 S
Jet max (kt)	130
Wind speed (kt)	50
Turbulence (g)	0.5
Time difference (hr)	-4

2.2 Flight 28, 9 Dec. 1969 - Events 16, 21, and 22/23 (Fig. 14 to 20)

These events all occurred over or near mountainous terrain and within 60 nautical miles of the jet stream (Fig. 15 and 18). Event 16 was a 12-minute event that displayed several waves in the temperature trace along with some g exceedances that were probably the result of autopilot-induced pitches (Fig. 14). About 2 minutes of light turbulence with very small temperature changes were recorded during Event 21 (Fig. 16) over terrain that was less mountainous than that of either Event 16 or 22/23. Event 22/23 (Fig. 17) shows a larger amplitude temperature wave recorded at 50,000 feet in the lee of the Chuska Mountains. The peak rate of change of temperature recorded during this event was -5°C in 16 seconds, i.e. in 2 nautical miles. As has often been observed in the Coldscan flights, temperature changes of this magnitude initiated aircraft pitching when the autopilot was in the Mach-hold mode.

The position of the jet stream is shown on the 300-mb analysis in Figure 19 and the rawinsonde data for Winnemucca, Nevada, is shown in Figure 20.

All of the events showed some evidence of mountain wave activity in the static temperature traces. The weakest waves (amplitude 1.5°C) were encountered during the turbulence-triggered Event 21. The turbulence appears to have occurred in the trough of a lee wave of very small amplitude.

The sawtooth-like variations in the Winnemucca temperature data were probably due to the sonde rising through lee waves (see Fig. 5, Ref. 1). Estimates of the wavelengths were made from these variations assuming a constant balloon ascent rate of 1000 ft/min and no phase shift of the waves in the vertical. Three waves between 153 and 71 mb had computed wavelengths of 6.3, 4.6, and 4.7 nautical miles. This is about half the 10 nautical mile wavelength estimated from the flight data for Event 16, some 100 miles southeast of Winnemucca. The difference could have resulted from an upstream tilt to the waves in the vertical or from different lower boundary conditions.

Event Data

Event number	16	21	22/23
Flight level (ft)	50,000	50,000	50,000
Terrain	Mts	Mts	Mts
Wavelength (n. mi)	10	12	7
Amplitude (°C)	2.0	1.5	3.5
Vertical velocity (ft/sec)	8	5	18
Distance from jet (n. mi)	60 N	60 S	60 S
Jet max (kt)	140	140	140
Wind speed (kt)	60	60	60
Turbulence (g)	-	0.3	-
Time difference (hr)	-1	0	0

2.3 Flight 30, 11 Dec. 1969 - Events 2, 5, and 6 (Fig. 21 to 26)

Although these three events were recorded at widely separated locations over the western United States (Fig. 24), the static temperature traces of all three events exhibit evidence of mountain wave activity. In addition to the well-formed waves in the temperature traces of Event 2 (Fig. 21), the indicated airspeed trace gives further evidence of the presence of mountain waves. Since the aircraft was being operated with the autopilot in the altitude-hold mode, each encounter with ascending air (as indicated by a minimum in the temperature trace) is accompanied by a slightly increased indicated airspeed. Similarly, flight in descending air causes a reduced airspeed. A satellite photograph of the area taken at 1713Z showed evidence of lee waves in the vicinity of Events 2 and 5. There was little or no cloud in the vicinity of Winnemucca when Event 6 occurred.

The 300-mb analysis of 00Z on December 12 is shown in Figure 25. Based on rawinsonde data, the jet stream had maximum winds at 35,000-38,000 feet. There were very large negative vertical wind shears above the jet stream up to the flight level of 50,000 feet. Typical values for Event 5, which occurred near the jet, were 8-10 knots per 1000 feet (Fig. 26). The other events had similar shears but of a slightly lower magnitude, 5-8 knots per 1000 feet.

Event 6 occurred in the same area as Events 16 and 18 of Flight 28 two days earlier. A comparison of the wavelengths shows that all three events had similar wavelengths, though those for Flight 28 had slightly lower amplitudes. In both cases there was westerly flow over the area at all levels, but in the earlier flight a jet stream was in the immediate area.

Recorder problems caused the unusually noisy total temperature traces for this flight, and the splice noise that appears at 2-minute intervals on all the traces.

Event Data

Event number	2	5	6
Flight level (ft)	50,000	50,000	50,000
Terrain	Mts	Mts	Mts
Wavelength (n. mi)	10	9	14
Amplitude (°C)	3	3	3
Vertical velocity (ft/sec)	6	8	6
Distance from jet (n. mi)	20 S	20 N	300 S
Jet max (kt)	140	140	140
Wind speed (kt)	35	40	50
Turbulence (g)	-	-	-
Time difference (hr)	-7	-6	-4

2.4 Flight 31, 12 Dec. 1969 - Events 1, 2, and A (Fig. 27 to 30)

All three events shown occurred downstream from a high pressure ridge well to the south of a well-developed jet stream.

The first event (Fig. 27) occurred at 49,000 feet over the southern portions of the Sangre de Cristo Mountains (Fig. 30). Almost 4 minutes of light to moderate turbulence was encountered with peak vertical accelerations of about 0.5 g. The static temperature trace shows little evidence of lee waves but it does indicate that the temperature had increased just prior to the beginning of the turbulence and that it decreased again after the turbulence had subsided.

The other two events occurred over the plains 120-200 miles downstream from the Sangre de Cristo Mountains. Event 2 (Fig. 28) exhibited a rapid increase in temperature of 3.5°C in 5 seconds (0.6 n. miles), which was not followed by any other significant changes. The final event (Fig. 29) consisted of a series of wave-like temperature disturbances of relatively short wavelength. Since they were not encountered on the outbound leg two hours before, they had either developed or intensified during this time or were travelling in the downwind direction. Measured doppler winds at 50,000 feet were westerly at 60 to 70 knots. The vertical velocity amplitude included in the tabulated event data was based on a standing gravity wave and would be an overestimate of that present in a moving wave system.

Event Data

Event number	1	2	A
Flight level (ft)	49,000	49,000	50,000
Terrain	Mts	Plains	Plains
Wavelength (n. mi)	-	-	5
Amplitude (°C)	-	-	2
Vertical velocity (ft/sec)	-	-	15
Distance from jet (n. mi)	500 S	300 S	330 S
Jet max (kt)	140	140	140
Wind speed (kt)	80	50	65
Turbulence (g)	0.5	-	-
Time difference (hr)	-6	-6	-3

2.5 Flight 34, 13 Jan. 1970 - Event 3 (Fig. 31 to 33)

This event occurred over the Pacific Ocean about 180 nautical miles south of the Panama Canal (Fig. 32). The 200-mb analysis for the area (Fig. 33) shows low wind speeds, little wind shear, and a lack of any major disturbance that may have contributed to the incident.

The event is significant, for although this was one of the few Coldscan flights to date that have been flown over ocean, a moderately large temperature gradient of 7°C in 36 seconds (4 n. miles) was encountered. The temperature change was measured during a slow climb from 56,000 to 57,000 feet in the lower stratosphere, where the recorded temperature rapidly increased from one quasi-constant level to another (Fig. 31). The cause of this increase was probably a sharp inversion layer just above the tropopause. The rate of change of measured temperature under these conditions is dependent on the rate of climb and would be much greater for an SST type of flight program.

Event Data

Event number	3
Flight level (ft)	55,000-57,000
Terrain	Ocean
Turbulence (g)	-
Time difference (hr)	3

2.6 Flight 42, 12 Feb. 1970 - Events 5 and 6 (Fig. 34 to 37)

These events occurred at 60,000 feet over the foothills 60 to 90 miles east of the Sangre de Cristo Mountains (Fig. 36). There was a west to northwesterly flow at all levels, with jet streams at 38,000 feet to the northwest and southeast of the events.

These two jets appeared to be formed from a split in a single jet, which apparently took place in the preceding few hours. The 300-mb analysis and event positions are shown in Figures 37 and 36.

Event 5 (Fig. 34) has an appearance of being lee-wave induced. The changes in static temperature are typical of those encountered under such conditions, as is also the relative position of the light turbulence, which coincided with the warm temperatures in the trough of the wave. Since this event occurred when the aircraft track was normal to the reported wind direction, it is probably representative of a temperature profile through a lee wave of the type caused by an isolated hill (Ref. 5). The wavelength and vertical velocity in the wave could not be computed in this case because the track was parallel to the wave crests.

Event 6 (Fig. 35) occurred over Conchas Lake, just west of Tucumcari, New Mexico. This event appeared to be caused by short mountain waves. The small wavelength, high wind speed, and large temperature fluctuations suggest that very high vertical velocities of up to 28 ft/sec occurred in these waves. The flow through these waves appears to have been fairly smooth. The vertical accelerations recorded were of low frequency and highly correlated with pitch attitude. It seems reasonable to assume that these resulted from the autopilot on the altitude-hold mode attempting to compensate for the high vertical wind speeds, rather than from turbulence.

Event Data

Event number	5	6
Flight level (ft)	60,000	60,000
Terrain	Foothills	Foothills
Wavelength (n. mi)	-	5 and 9
Amplitude (°C)	3	4
Vertical velocity (ft/sec)	-	28 and 15
Distance from jet (n. mi)	80 S and 240 N	240 S and 80 N
Jet max (kt)	110	110
Wind speed (kt)	20	60
Turbulence (g)	0.2	-
Time difference (hr)	-4	-4

2.7 Flight 45, 17 Feb. 1970 - Event A (Fig. 38 to 40)

This event (Fig. 38) occurred at 45,000 feet just before the aircraft passed over the highest point of the Continental Divide (Fig. 39). The flow at all levels was normal to the ridge and the winds were especially high, with a maximum of 140 knots reported at 35,000 feet and doppler winds of 75 knots recorded at the flight level. The Denver sounding shown in Figure 40 is representative of the area.

The static temperature trace, the geographical position, and the wind field all suggest that the event was caused by a well-developed standing wave. This was further confirmed by the presence of a "cap" cloud on Pikes Peak to the west of Colorado Springs.

Event Data

Event number	A
Flight level (ft)	45,000
Terrain	Mountains
Wavelength (n. mi)	16
Amplitude (°C)	3
Vertical velocity (ft/sec)	7
Distance from jet (n. mi)	20 S
Jet max (kt)	140
Wind speed (kt)	75
Turbulence (g)	-
Time difference (hr)	-7

2.8 Flight 46, 18 Feb. 1970 - Event 1 (Fig. 41 and 42)

There was very strong west-southwesterly flow at all levels over the area of this event, with measured doppler winds of 130 knots from 250° at 51,000 feet. The turbulence event (Fig. 41) occurred about 10 miles east of the Continental Divide (Fig. 42) while the aircraft was flying normal to the wind field. The conditions were ideal for lee-wave development and it is probable that the 3.8 minutes of light to moderate turbulence and the temperature changes were caused by such waves. The relationship between the turbulence and the trough of the lee wave cannot be examined in this case since the flight was made along the direction of the wave crests. The variation of the static temperature was probably due to the non-uniformity of the waves across the flow caused by the uneven nature of the underlying terrain.

Event Data

Event number	1
Flight level (ft)	51,000
Terrain	Mountains
Distance from jet (n. mi)	120 S
Jet max (kt)	170
Wind speed (kt)	130
Turbulence (g)	0.5
Time difference (hr)	+5

2.9 Flight 47, 20 Feb. 1970 - Event 3/4 (Fig. 43 to 45)

The most interesting event of Flight 47 was a 35-second encounter with moderate turbulence while in a turn at 50,000 feet over Prescott, Arizona (Fig. 43 and 44). A peak positive acceleration increment of 1.0 g was measured, about 1/3 of which was a result of the turn. Doppler winds at flight level were from 240° at 70 knots. The Winslow rawinsonde data (Fig. 45) show that winds were generally southerly, veering from southeasterly at the lowest levels to southwesterly at 50,000 feet.

The temperature variations near the end of the event were probably caused by mountain waves originating from the ranges south and east of the Prescott VORTAC. It is difficult to estimate whether the aircraft flew through a lee-wave train, or through two separate mountain waves associated with the two ranges. The vertical velocities and wavelengths given below are based on the assumption that it was a lee-wave train.

The turbulence appears to be associated with the waves and is unusual in that it appears to coincide with the lower temperatures of the wave crests.

Event Data

Event number	3/4
Flight level (ft)	50,000
Terrain	Mountains
Wavelength (n. mi)	15
Amplitude (°C)	3
Vertical velocity (ft/sec)	7
Distance from jet (n. mi)	400 N
Jet max (kt)	90
Wind speed (kt)	70
Turbulence (g)	0.7
Time difference (hr)	-4

2.10 Flight 51, 27 Feb. 1970 - Event 11 (Fig. 46 to 48)

Eleven events were recorded on Flight 51, most of them being the result of g exceedances due to pilot and autopilot inputs. Three events showed temperature changes greater than 2.5°C in 30 seconds, with the illustrated traces of Event 11 (Fig. 46) showing the most rapid changes. The g excursions shown for Event 11 were mainly due to autopilot control inputs, but some very light turbulence (0.1 g) was possible. This event occurred over mountains when the winds were moderately strong and westerly at all levels. The winds and temperatures for the Denver sounding are shown in Figure 48.

The static temperature fluctuations were probably due to mountain waves associated with the 10,000 to 12,000-foot peaks northwest of Cheyenne. Since the flight path was normal to the wind direction, it is not possible to estimate the wavelengths of the associated vertical velocities.

Event Data

Event number	11
Flight level (ft)	50,000
Terrain	Mountains
Wavelength (n. mi)	-
Amplitude (°C)	3
Vertical velocity (ft/sec)	-
Distance from jet (n. mi)	300 S
Jet max (kt)	150
Wind speed (kt)	60
Turbulence (g)	0.1
Time difference (hr)	+7

2.11 Flight 53, 2 March 1970 - Events 1, 2, and 4 (Fig. 49 to 54)

Three events were selected from Flight 53 for detailed presentation, the first two being the result of rapid temperature changes and the last being a turbulence encounter in the absence of appreciable temperature variation. The 300-mb analysis for this date is shown in Figure 54.

The first two events were probably triggered by mountain waves. Event 1 (Fig. 49) occurred over the Sandia Mountains northeast of Albuquerque, and Event 2 (Fig. 50) was recorded to the lee of the southern tip of the Sangre de Cristo Mountains (Fig. 51). Waves of this type have been observed before over these ranges on other Coldscan flights. The hump in the static temperature trace of Event 1 (Fig. 49) contains temperature gradients at 50,000 feet of +7°C in 4 nautical miles and -5°C in 2.2 nautical miles. The flight through these waves was relatively smooth, with the only appreciable vertical accelerations being a result of a slight autopilot-induced pitching.

Event 4 (Fig. 52) occurred near Tulsa over a weak jet, well downstream from the jet maximum. The winds were west-southwesterly at about 70 knots from the tropopause up to 55,000 feet. It is unlikely that the turbulence was associated with the jet stream alone. There were reports of a thunderstorm in the area after the time of the event, but the navigator did not mention any severe activity in the area.

Event Data

Event number	1	2	4
Flight level (ft)	50,000	50,000	50,000
Terrain	Mts	Mts	Plains
Wavelength (n. mi)	20	20	-
Amplitude (°C)	4	4	-
Vertical velocity (ft/sec)	8	7	-
Distance from jet (n. mi)	150 N	150 N	0
Jet max (kt)	110	110	110
Wind speed (kt)	70	50	70
Turbulence (g)	-	-	0.4
Time difference (hr)	+6	+6	+7

3.0 ACKNOWLEDGEMENTS

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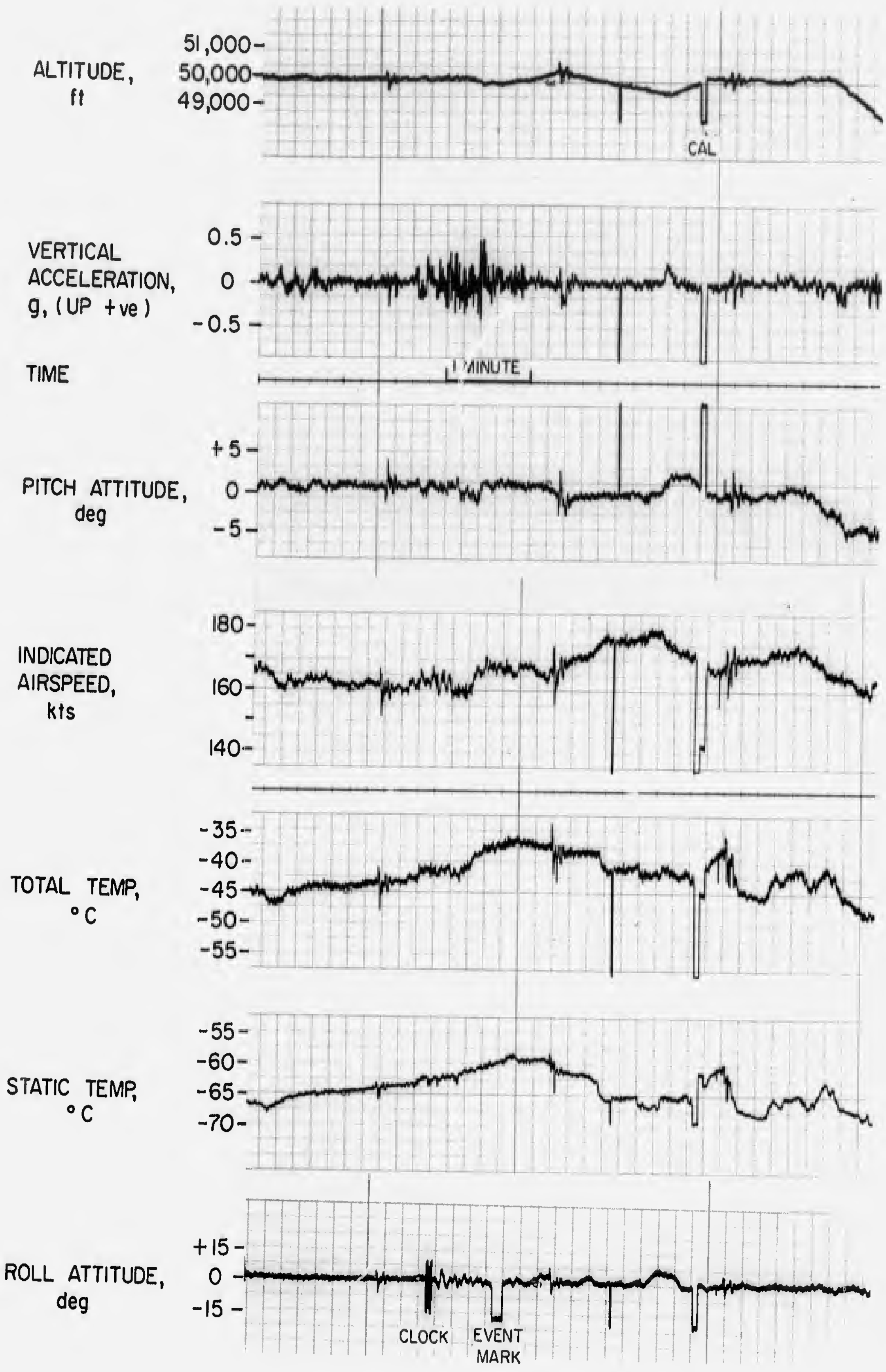


FIG. 11: FLIGHT 26, EVENT 6

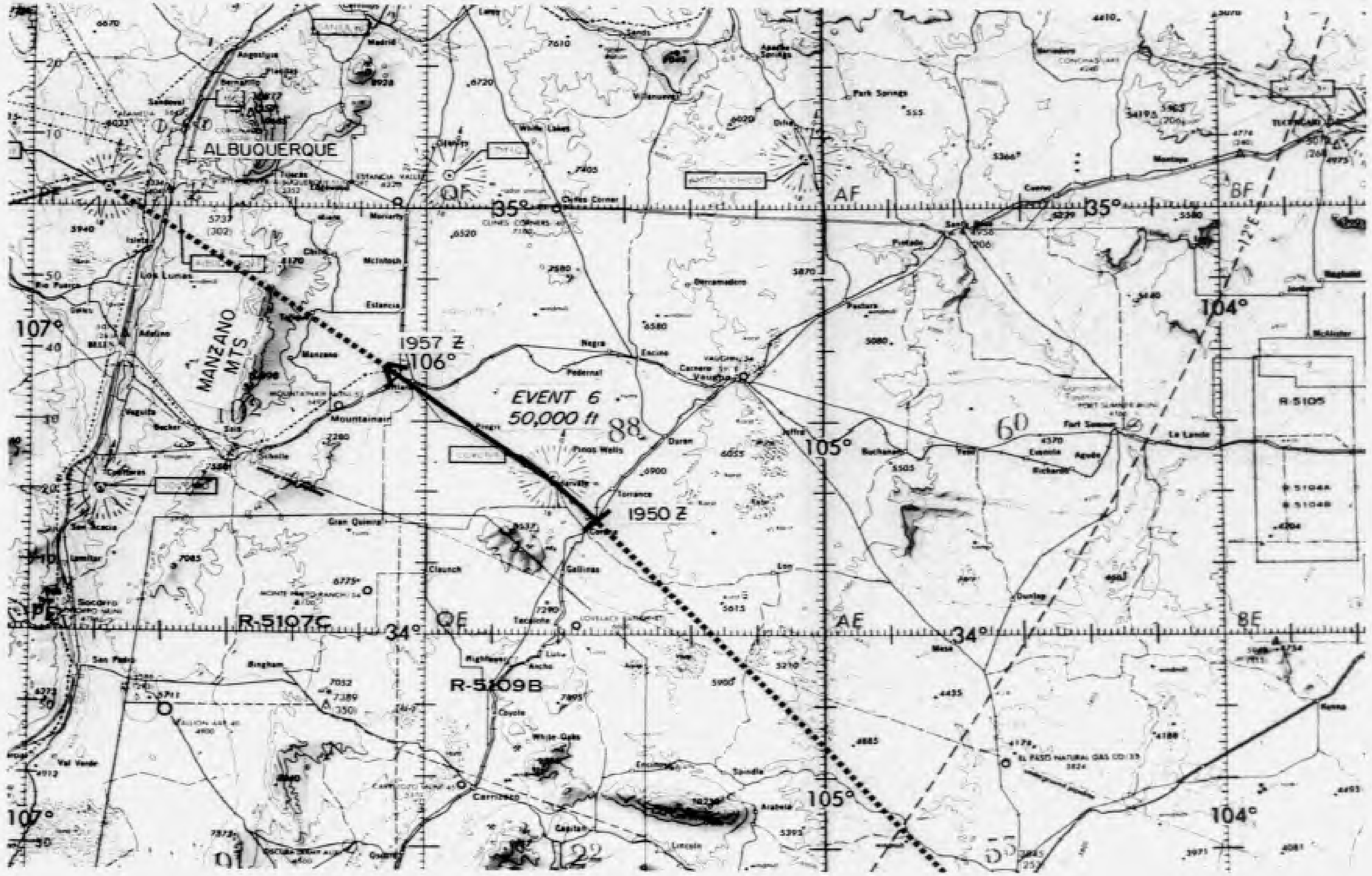


FIG. 12: FLIGHT TRACK SHOWING EVENT 6 OF FLIGHT 26, 3 OCT 1969

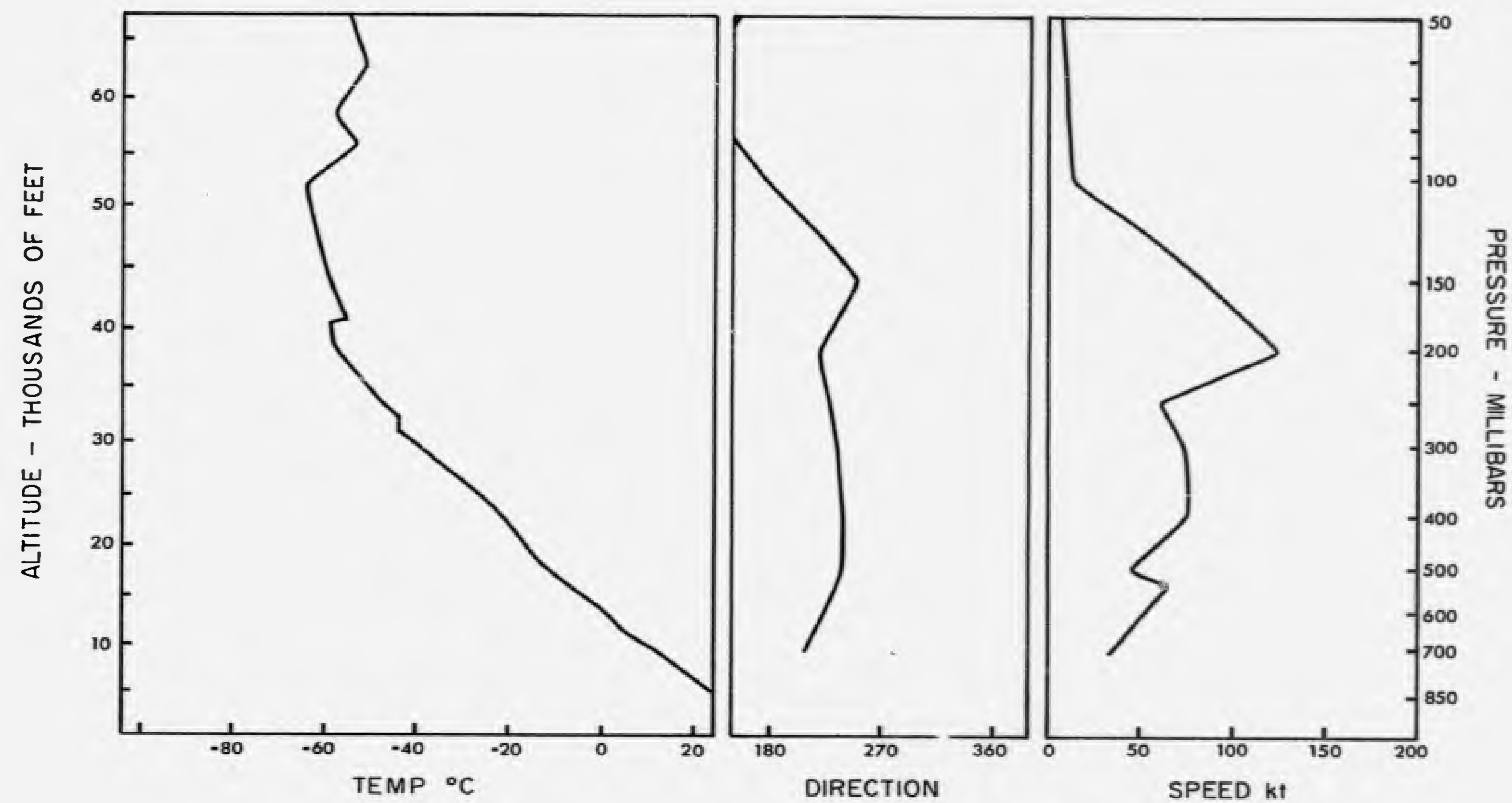


FIG. 13: UPPER AIR DATA

ALBUQUERQUE, N M

0000 GMT 4 OCT 1969

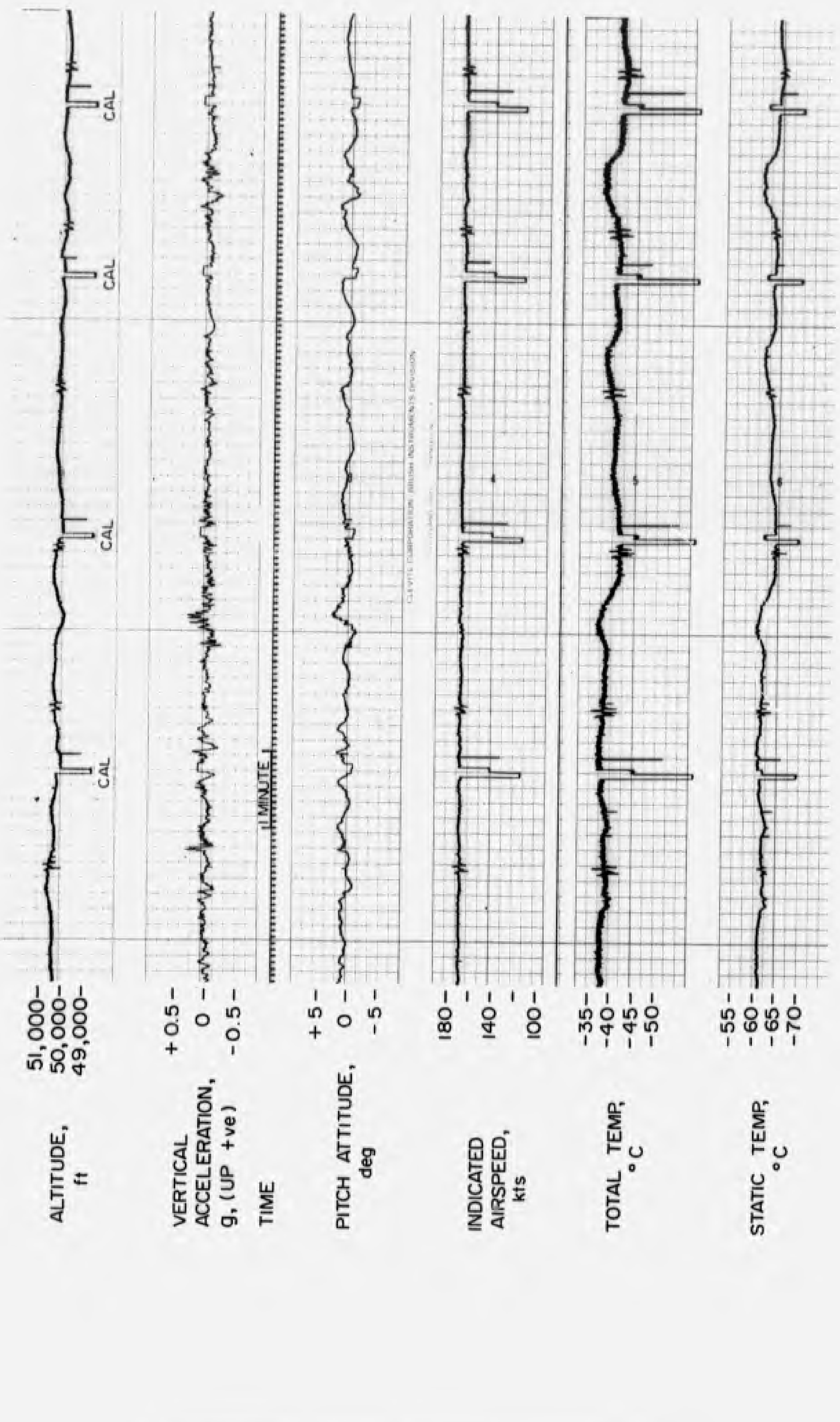


FIG.14: FLIGHT 28, EVENT 16

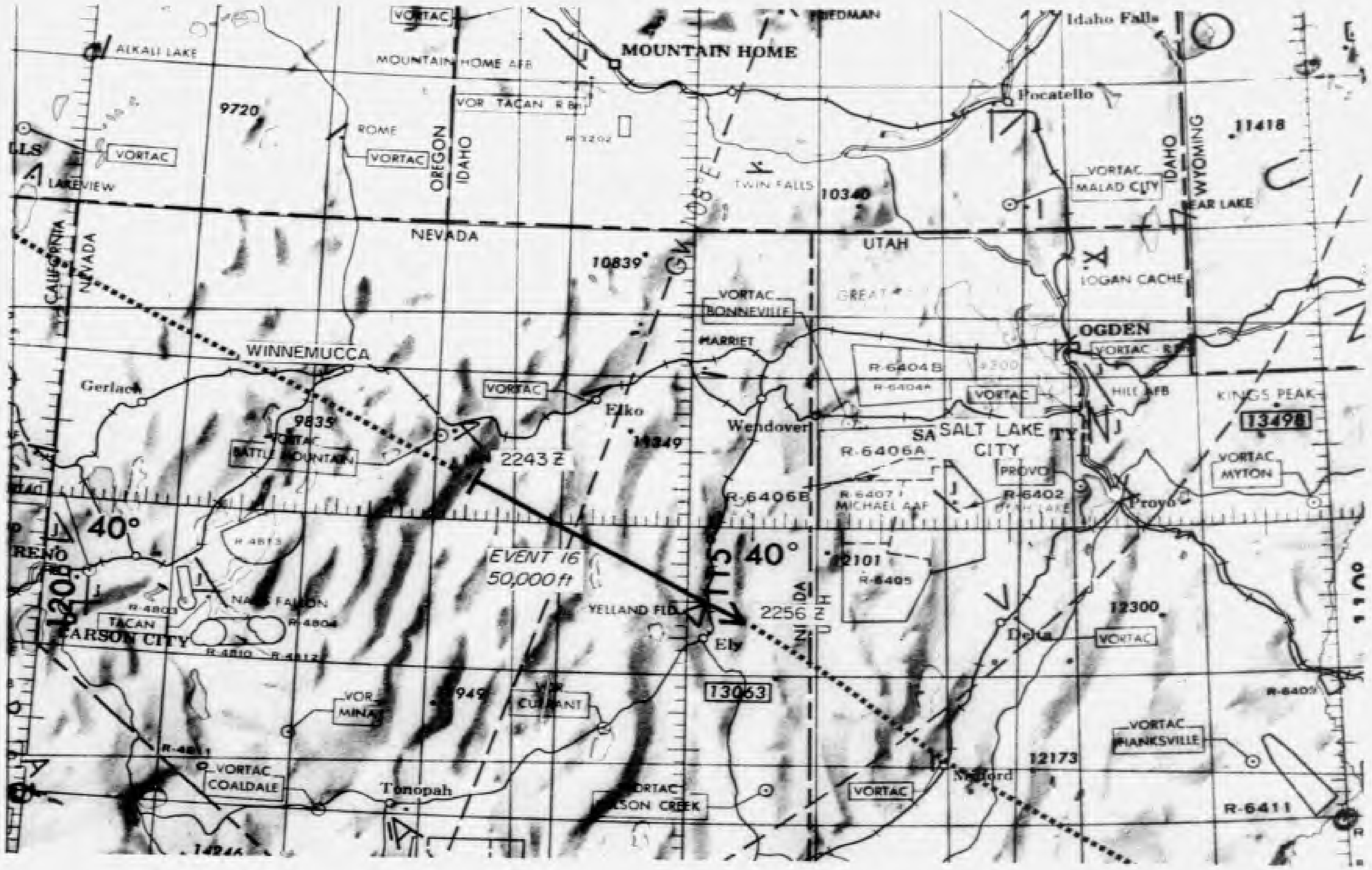


FIG. 15: FLIGHT TRACK SHOWING EVENT 16 OF FLIGHT 28, 9 DEC 1969

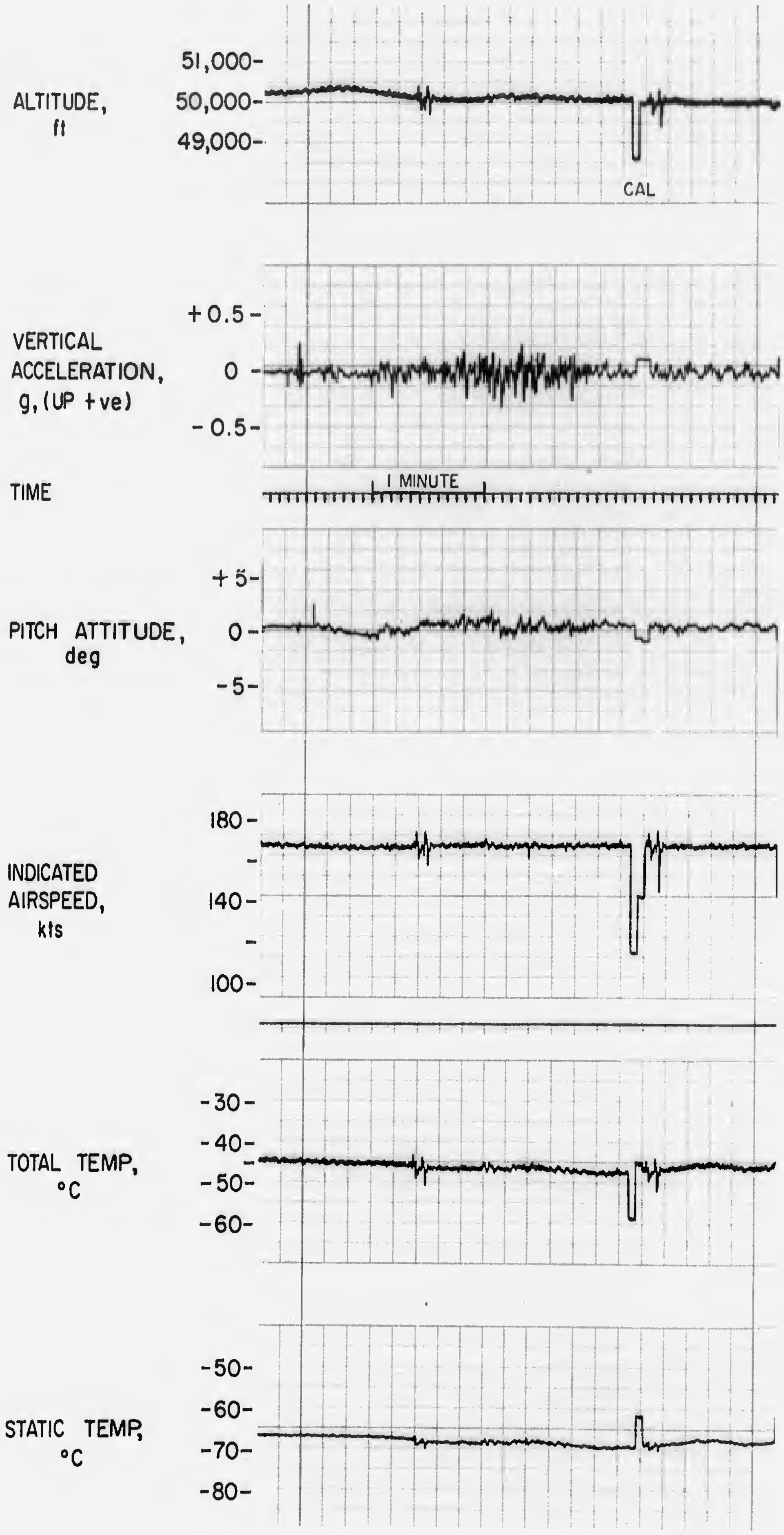


FIG.16: FLIGHT 28, EVENT 21

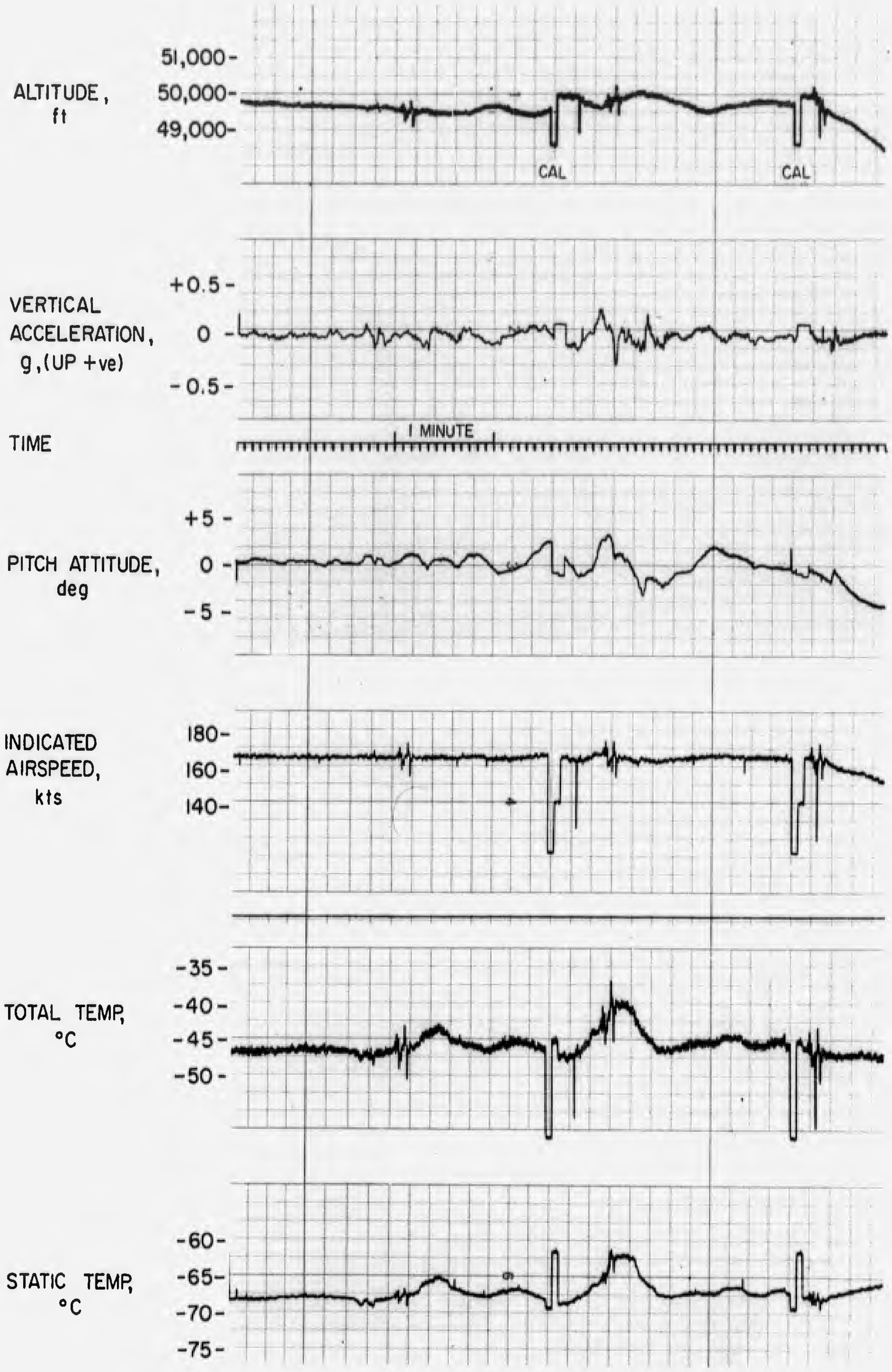


FIG.17: FLIGHT 28, EVENT 22/23

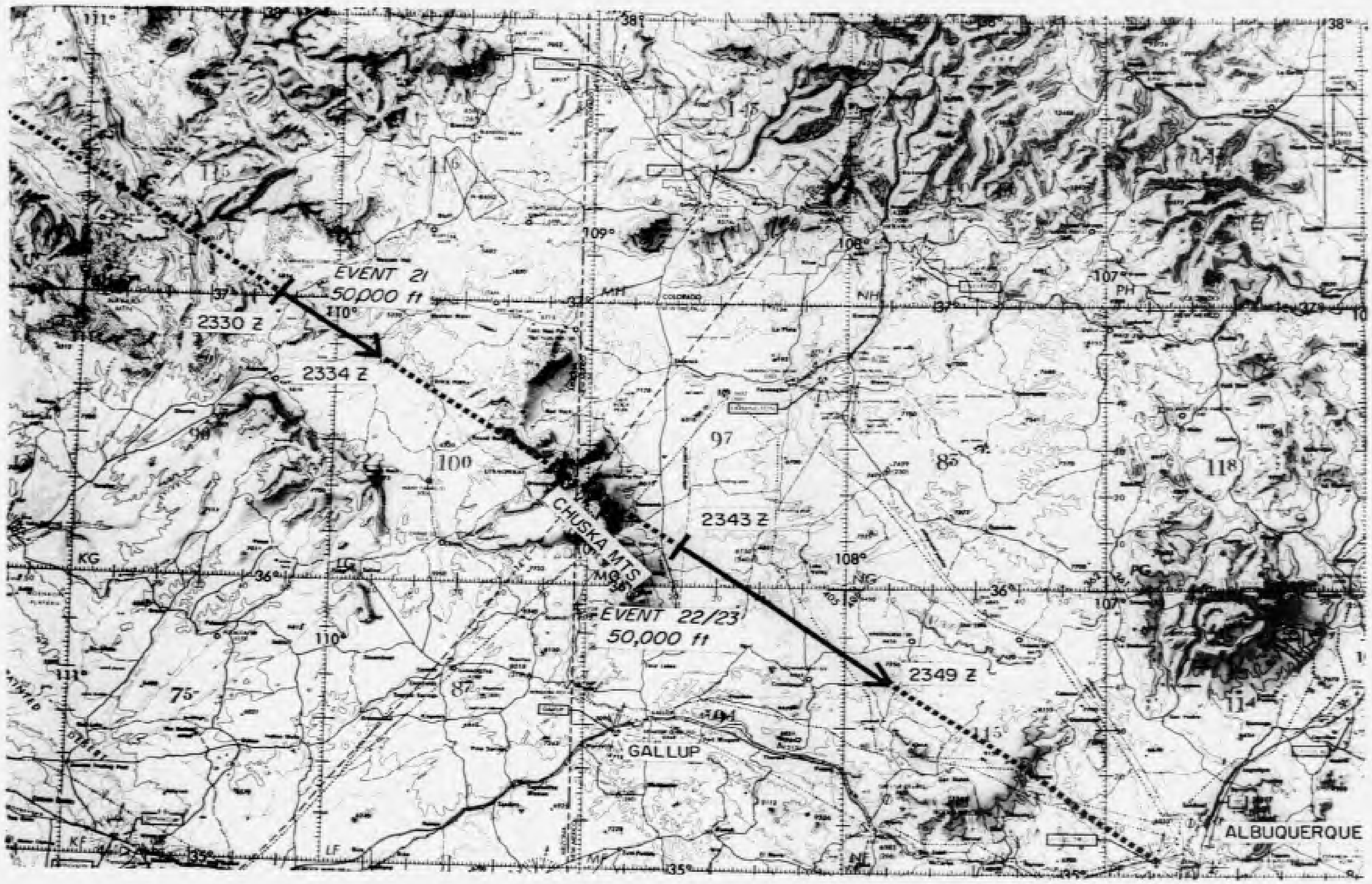
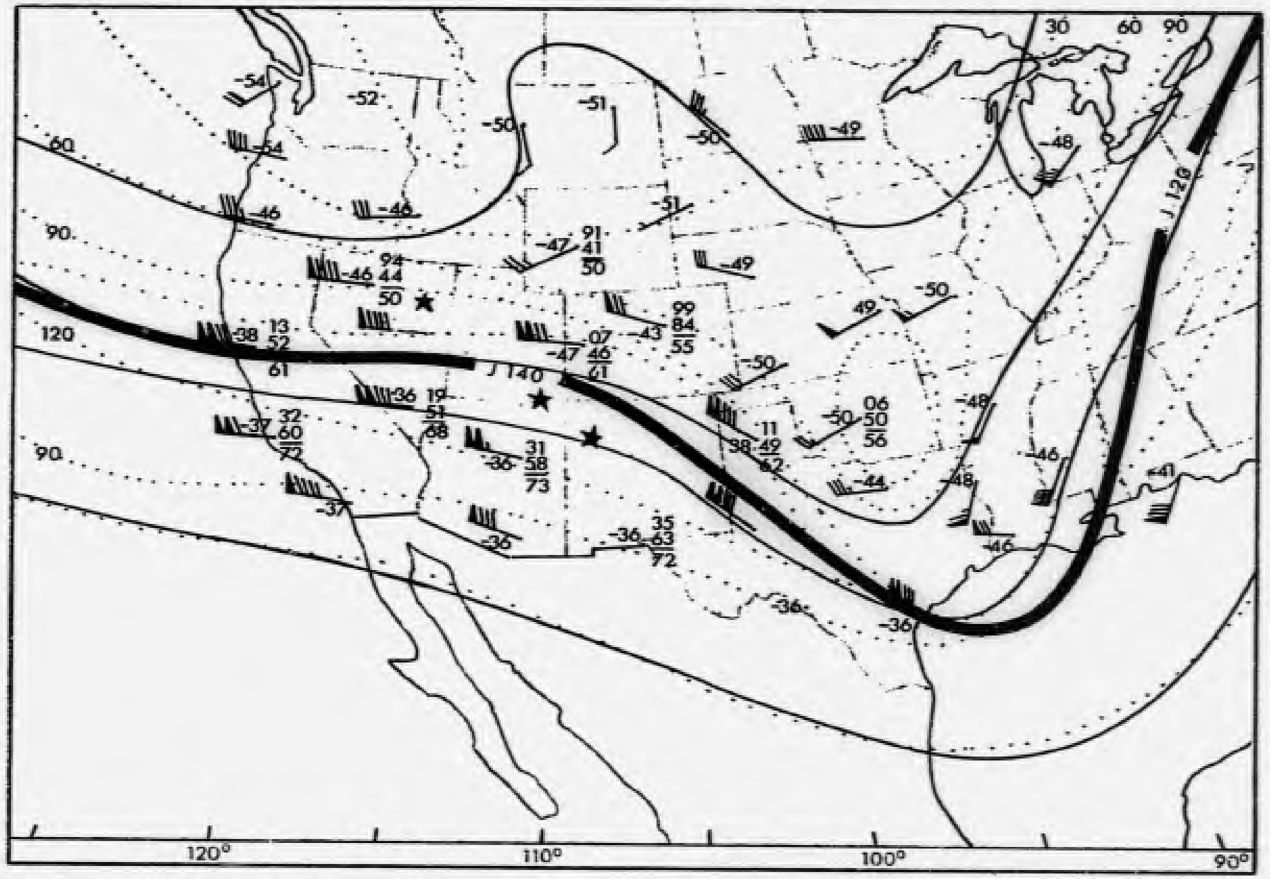


FIG.18: FLIGHT TRACK SHOWING EVENTS 21 AND 22/23 OF FLIGHT 28, 9 DEC 1969



★ POSITION OF EVENTS

FIG. 19: 300-MB ANALYSIS, 0000 GMT, 10 DEC 1969

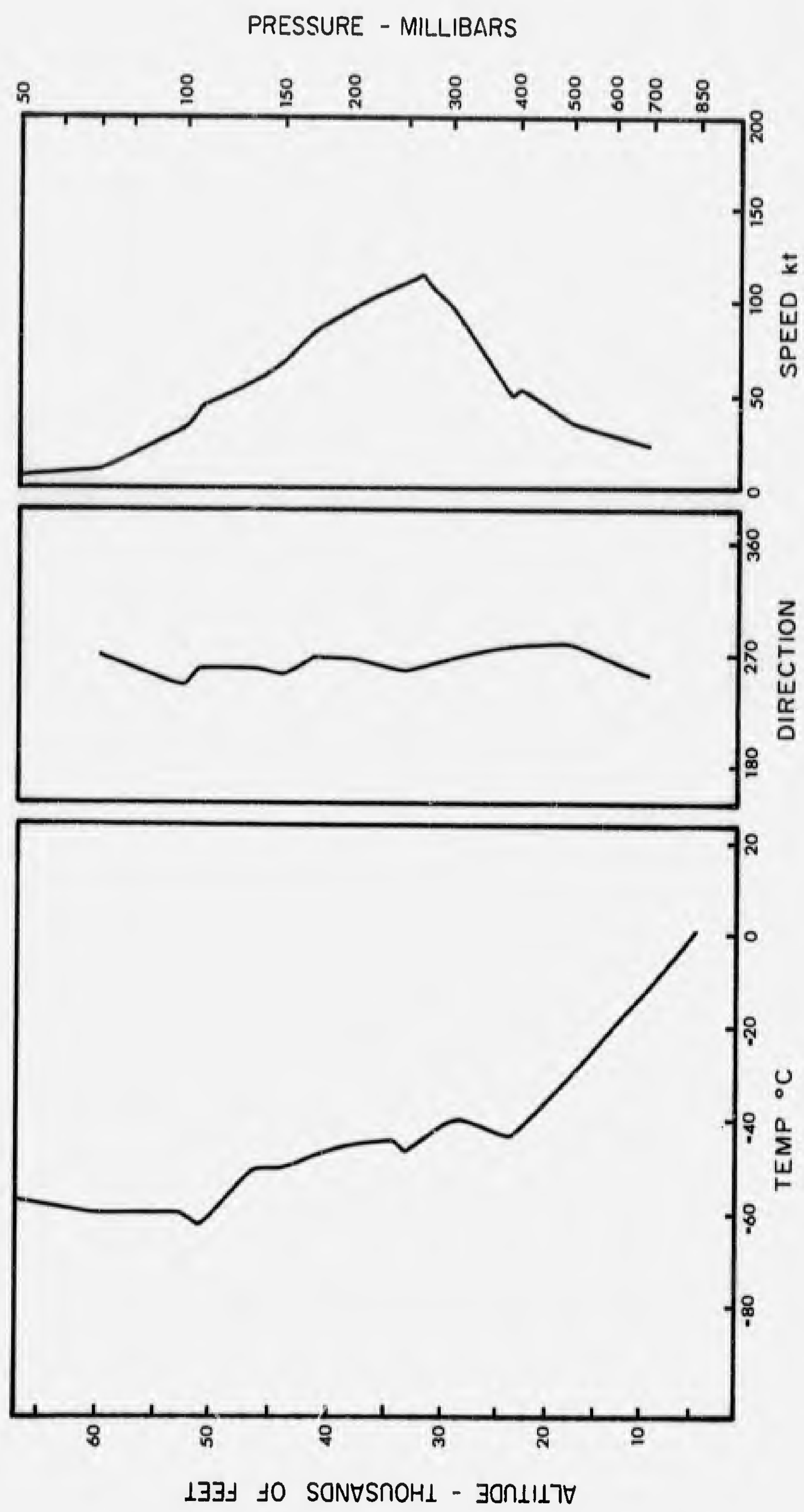


FIG. 20: UPPER AIR DATA

WINNEMUCCA, NEVADA

0000 GMT 10 DEC 1969

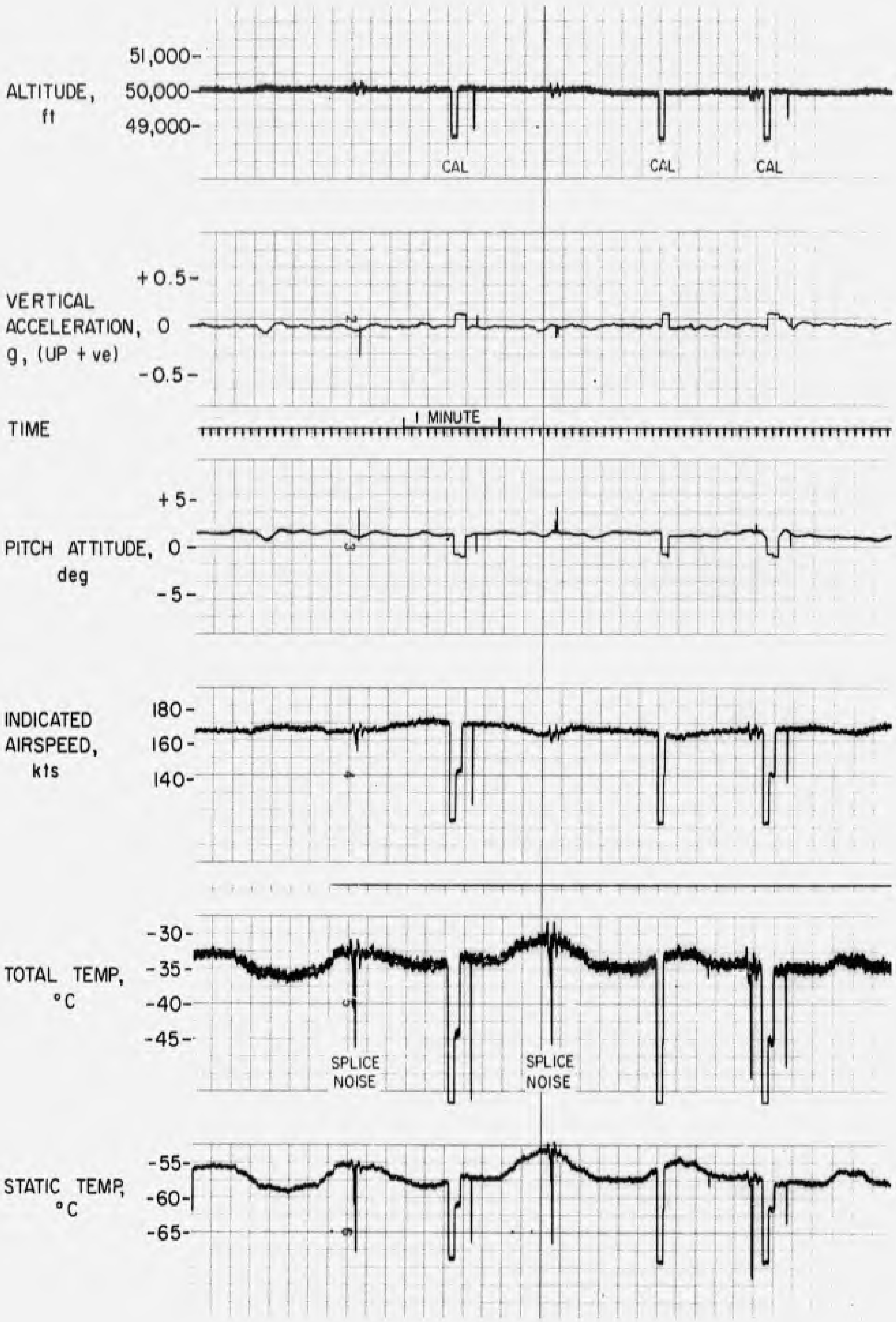


FIG. 21: FLIGHT 30, EVENT 2

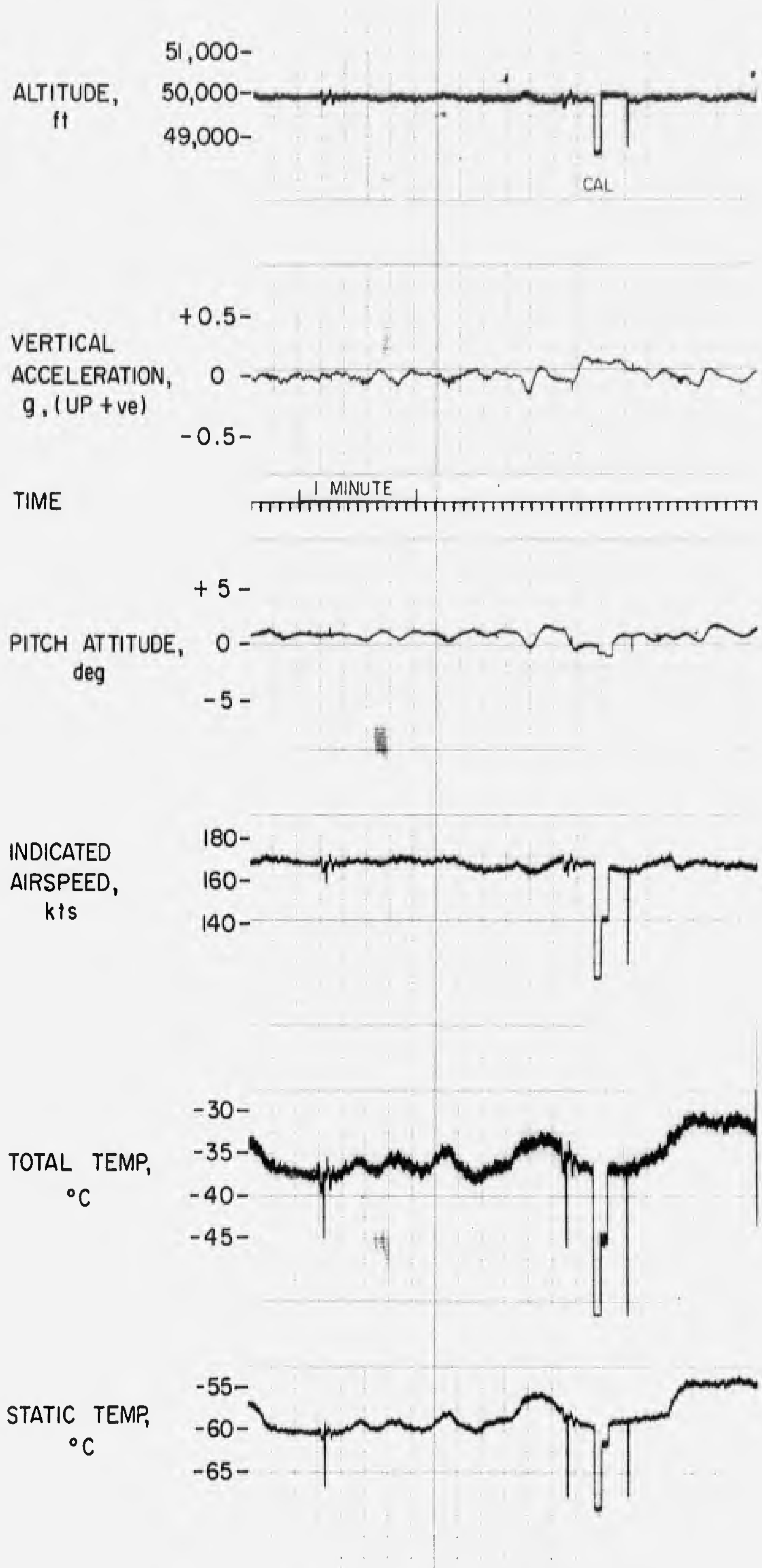


FIG. 22: FLIGHT 30, EVENT 5

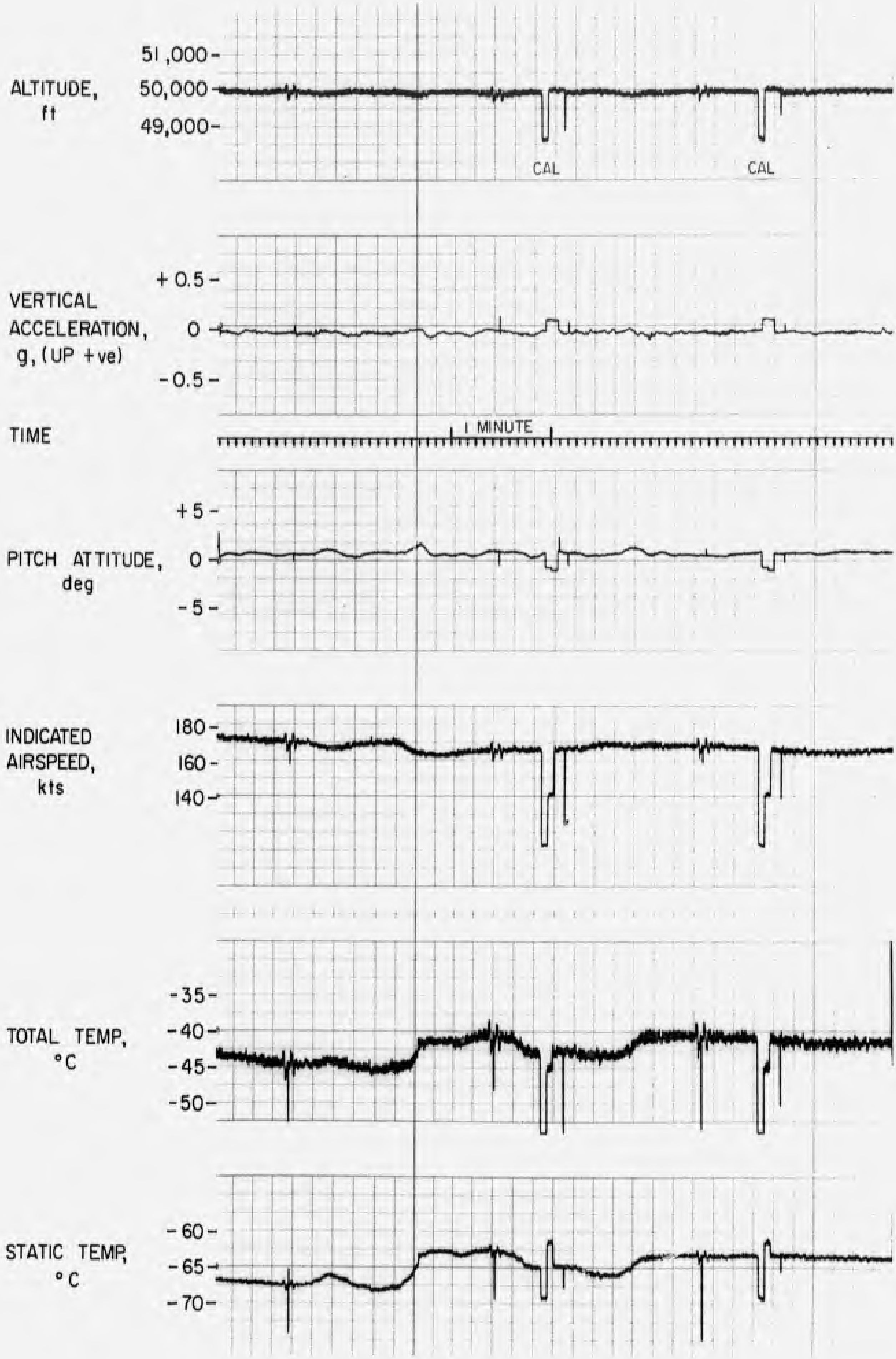


FIG. 23: FLIGHT 30, EVENT 6

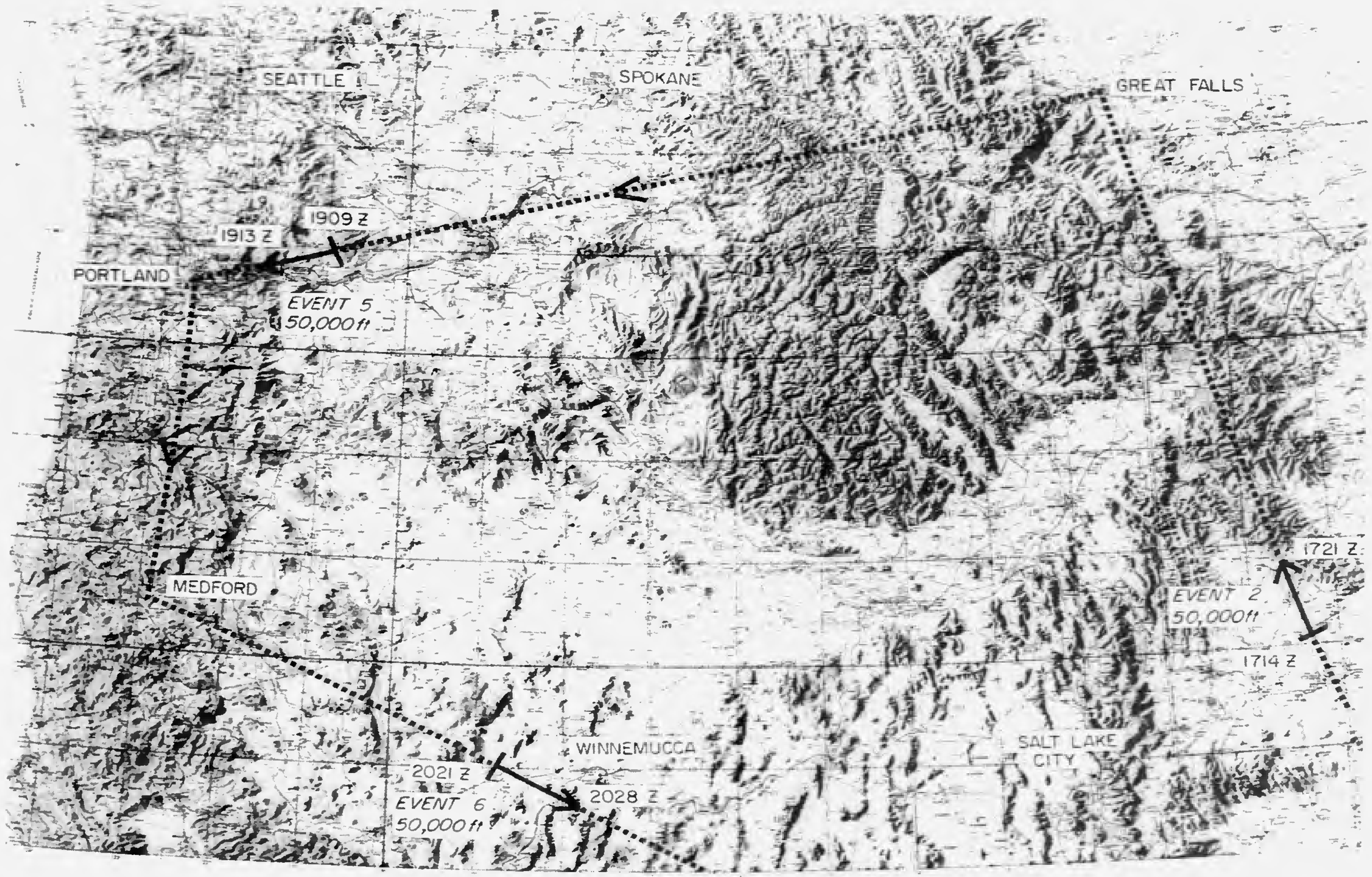


FIG. 24: FLIGHT TRACK SHOWING EVENTS 2,5 AND 6 OF FLIGHT 30, 11 DEC 1969

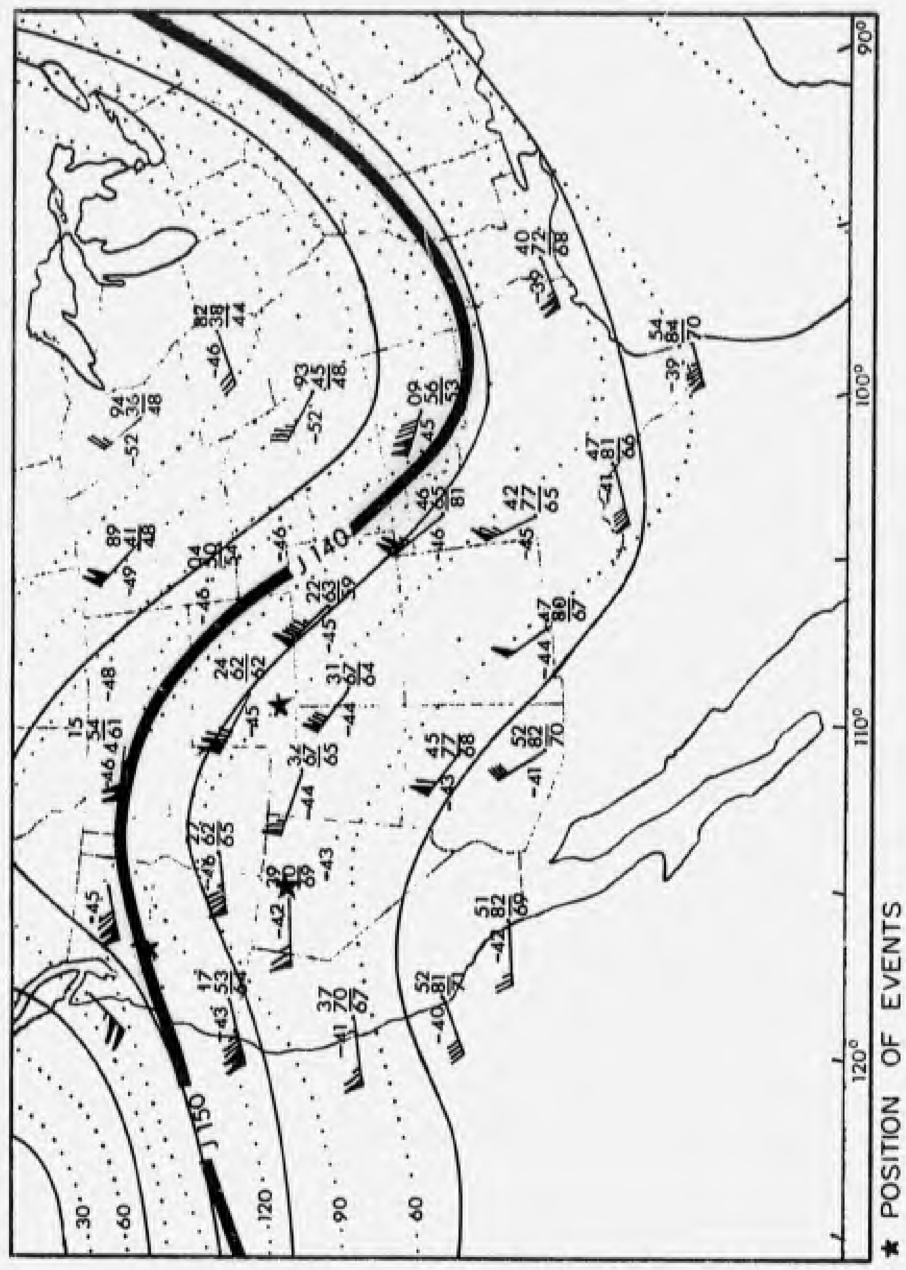


FIG. 25: 300-MB ANALYSIS, 0000 GMT, 12 DEC 1969

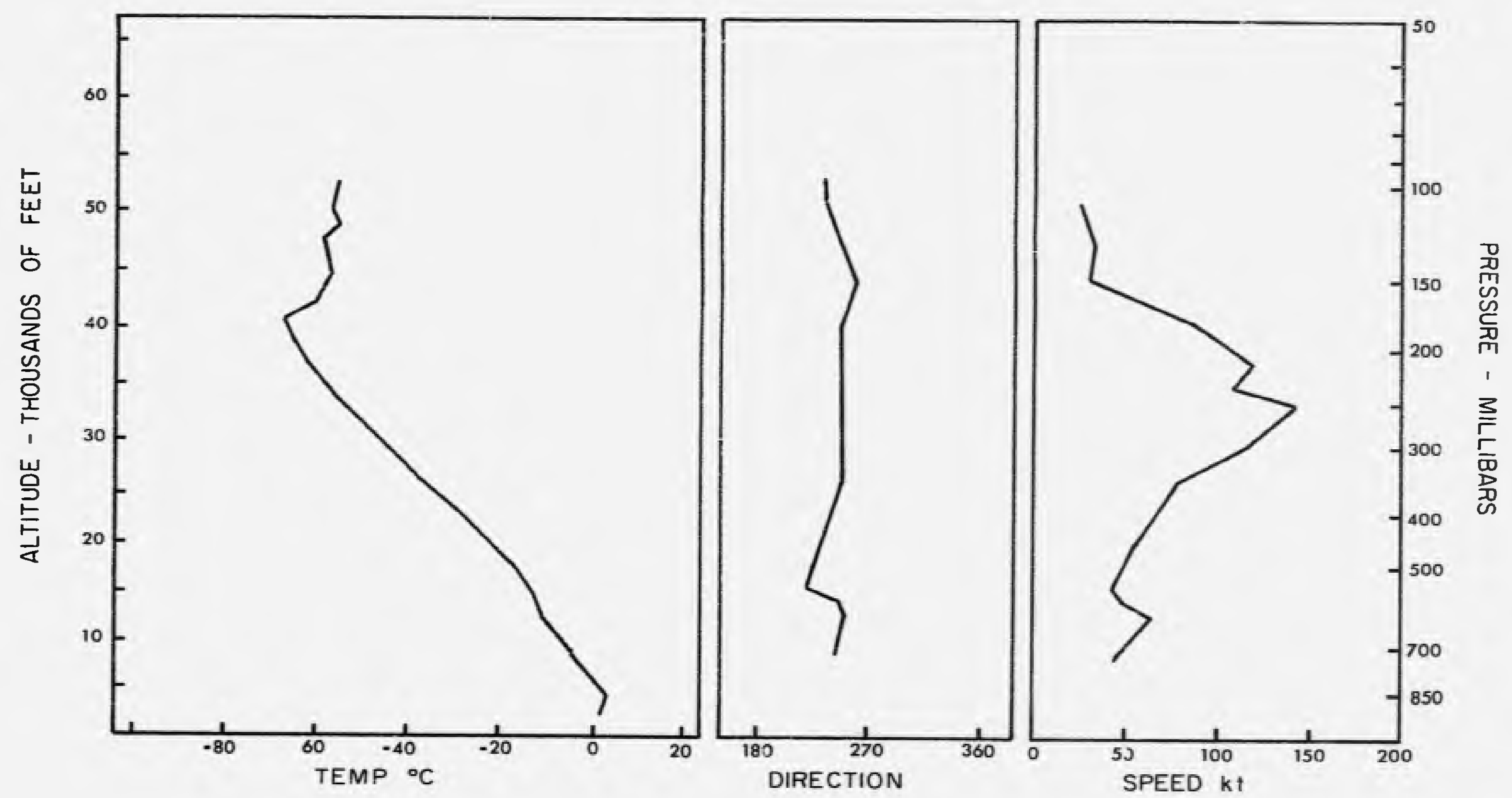


FIG. 26: UPPER AIR DATA

SPOKANE, WASHINGTON

0000 GMT 12 DEC 1969

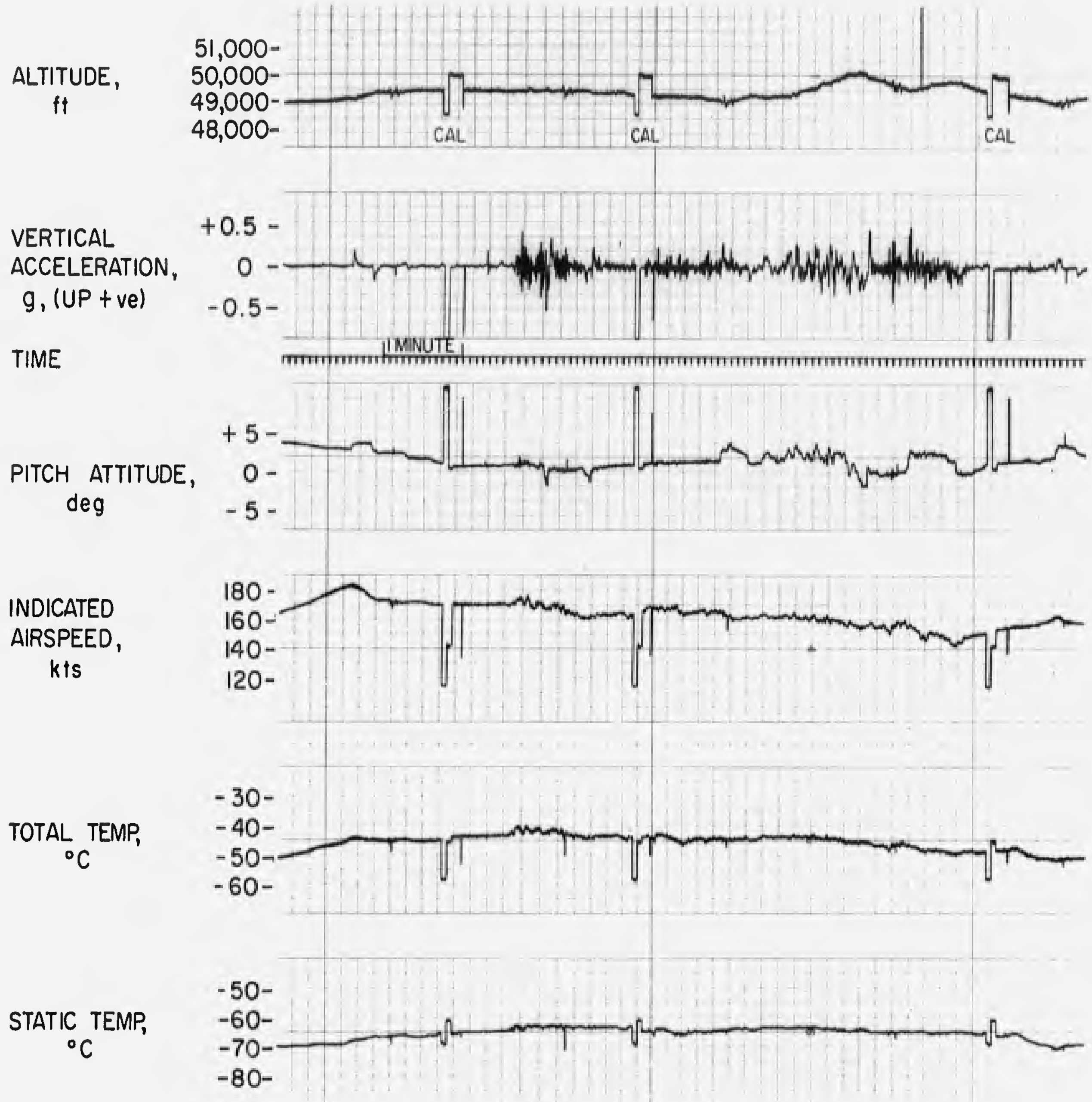


FIG.27: FLIGHT 31, EVENT I

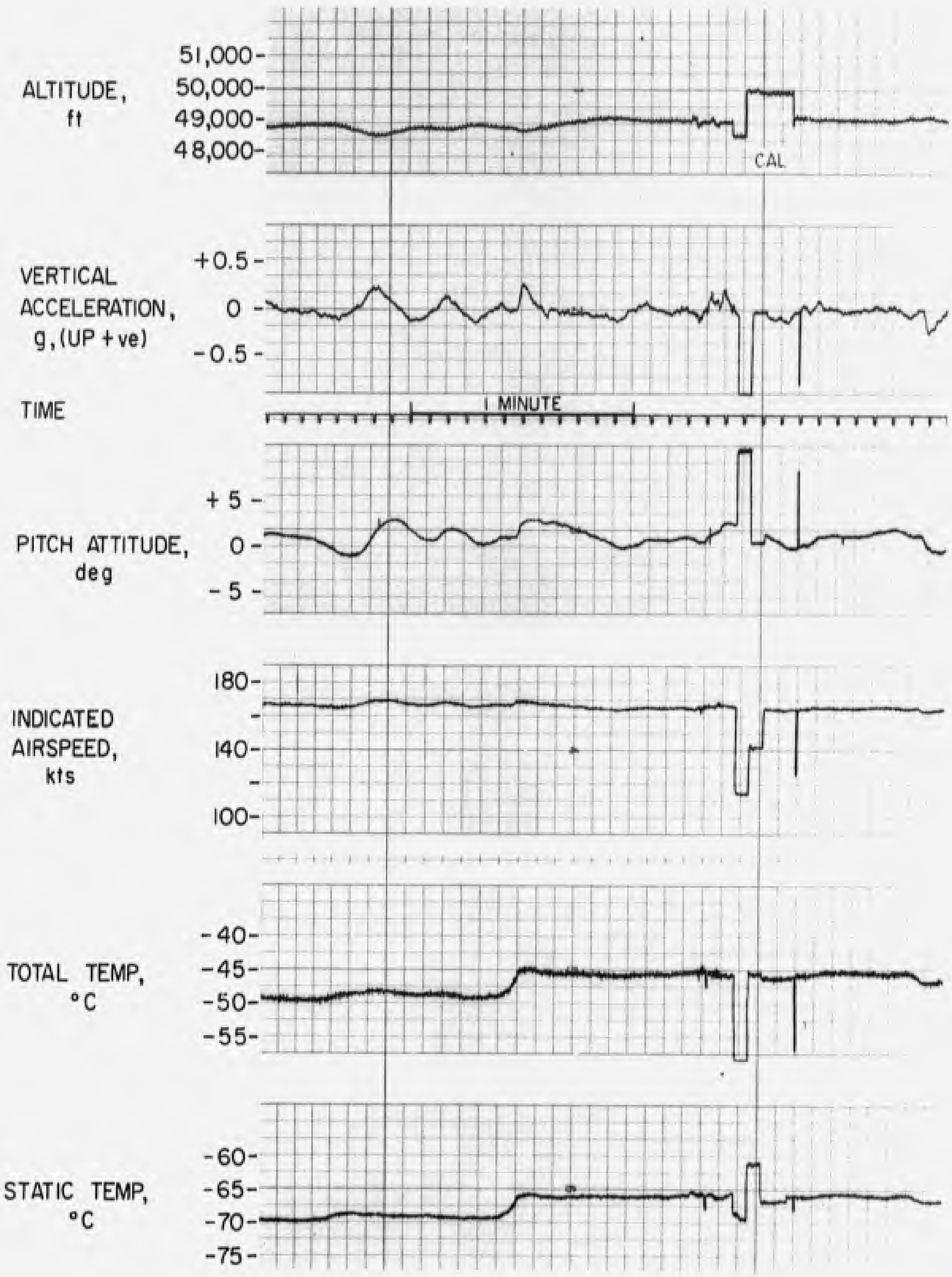


FIG. 28: FLIGHT 31, EVENT 2

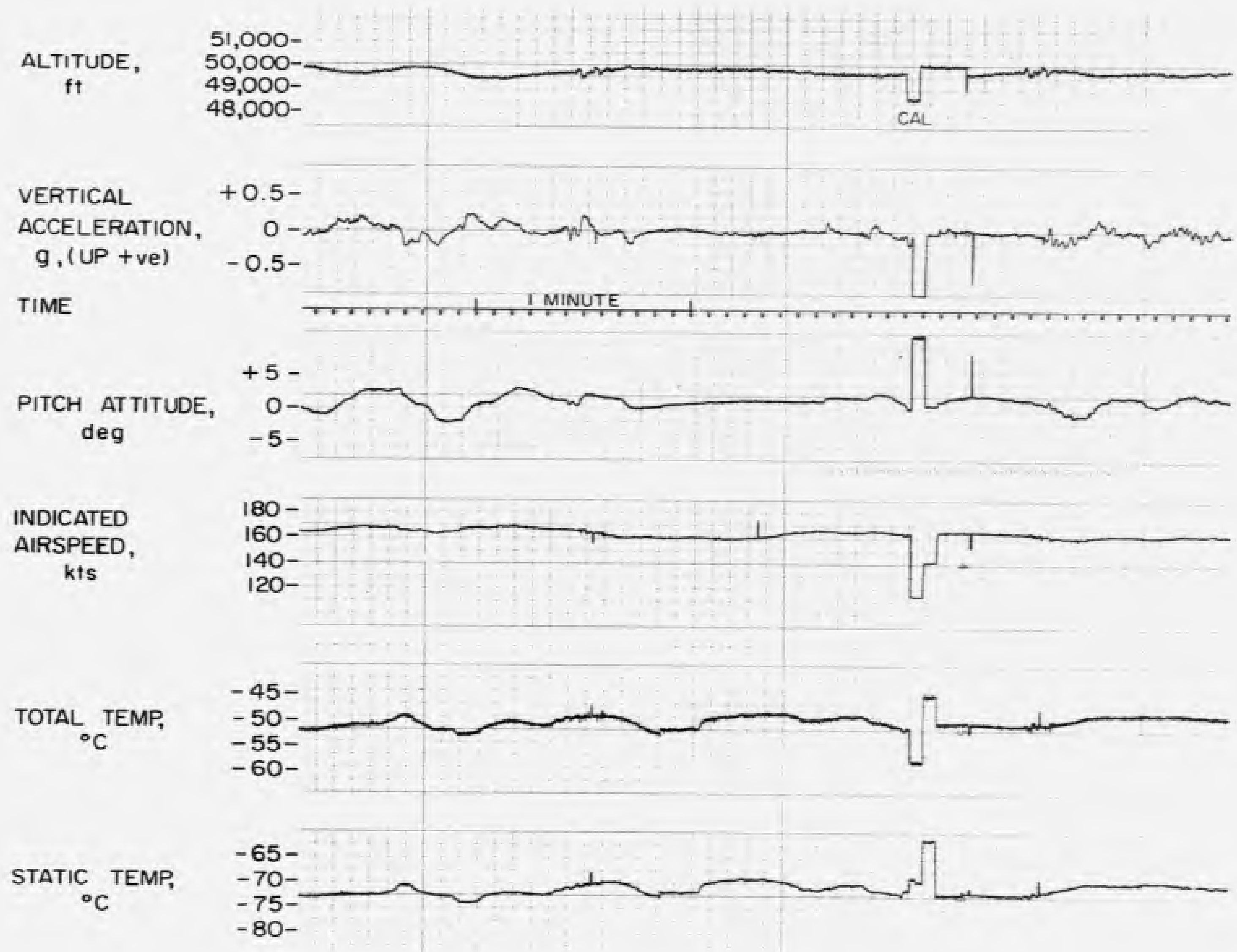


FIG. 29: FLIGHT 31, EVENT A

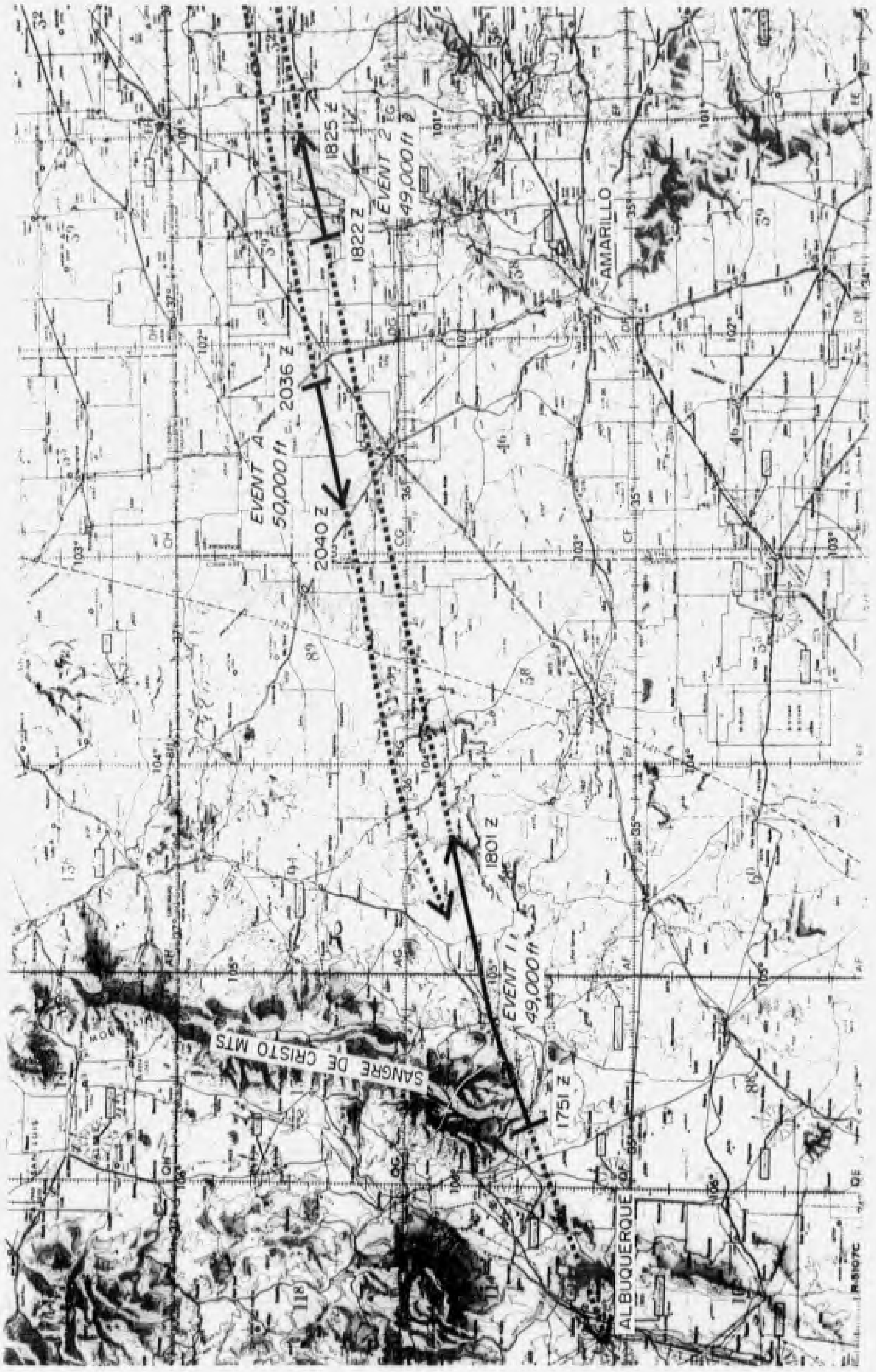


FIG.30: FLIGHT TRACK SHOWING EVENTS 1,2 AND A OF FLIGHT 31, 12 DEC 1969

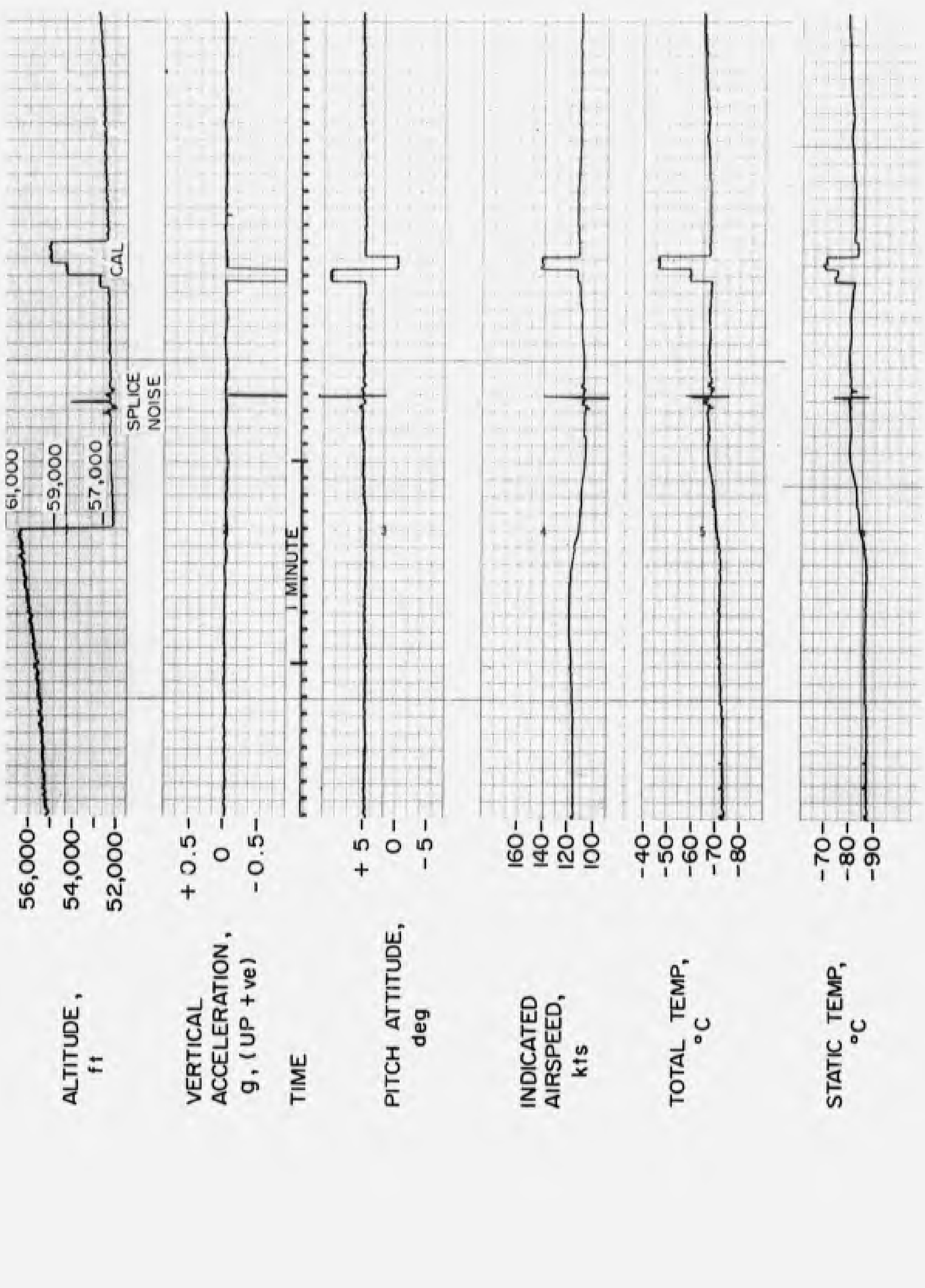


FIG. 31: FLIGHT 34, EVENT 3

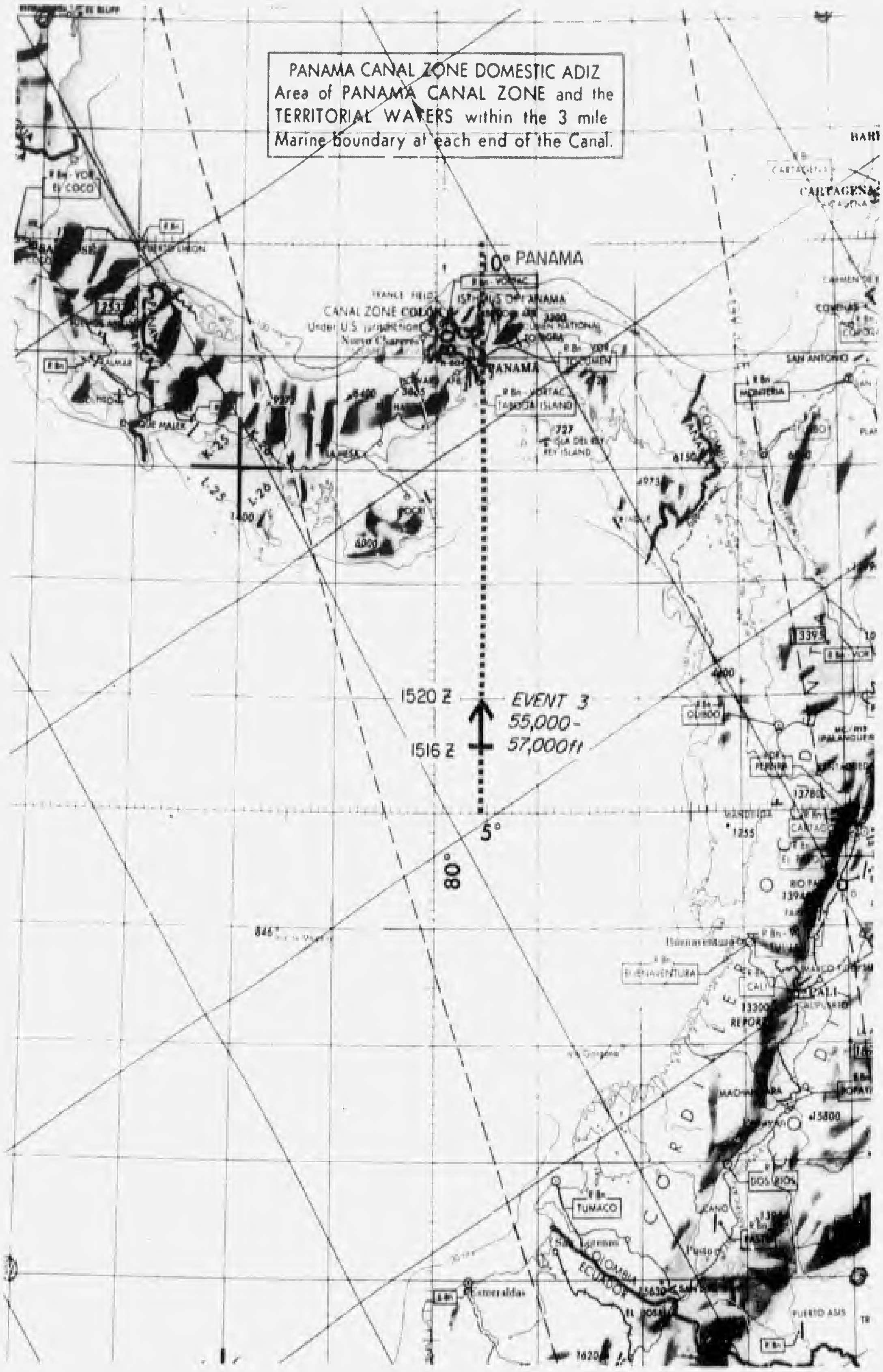
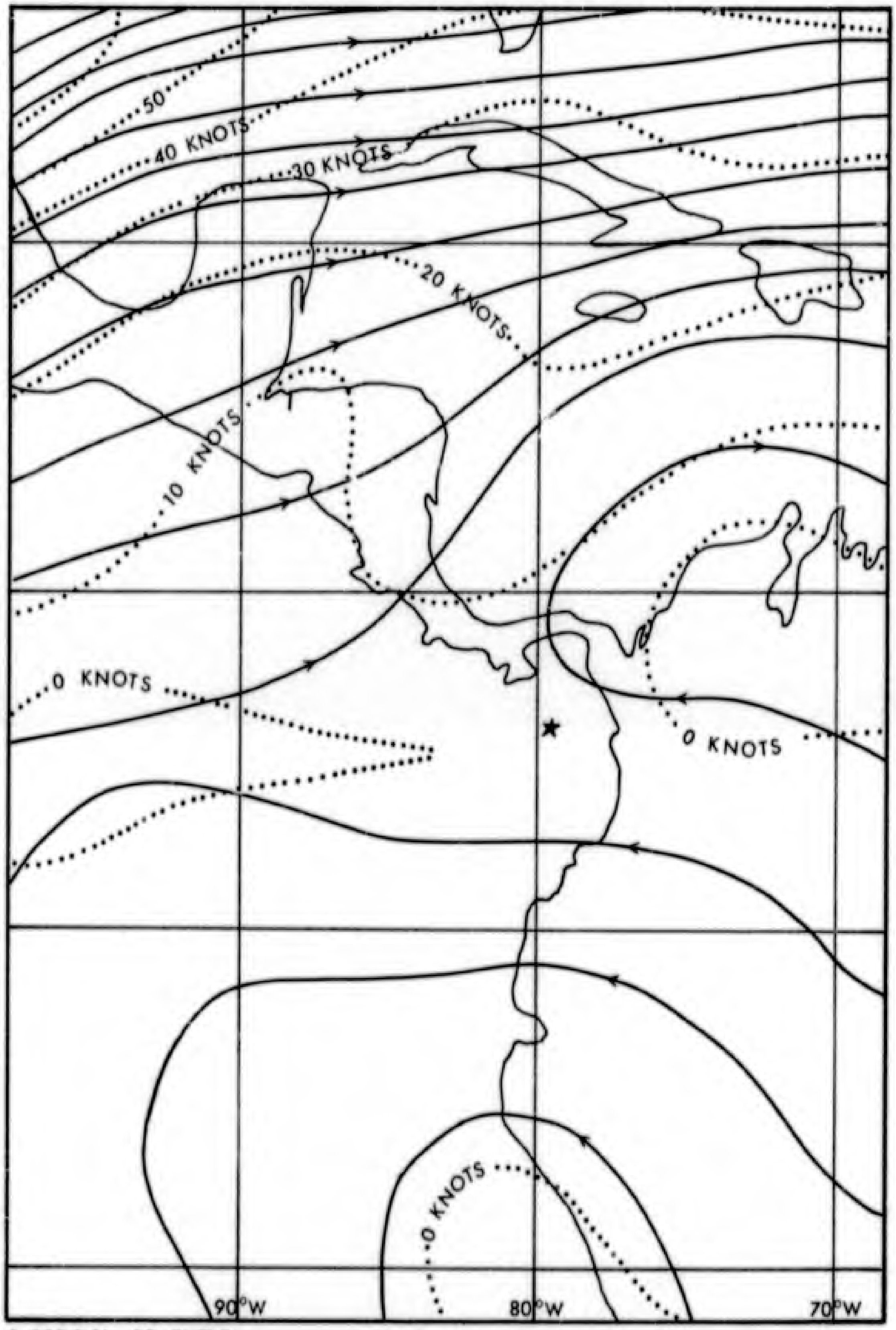


FIG. 32: FLIGHT TRACK SHOWING EVENT 3 OF FLIGHT 34, 13 JAN 1970



★ POSITION OF EVENT

FIG. 33: 200-MB STREAMLINE ANALYSIS, 1200 GMT, 13 JAN 1970

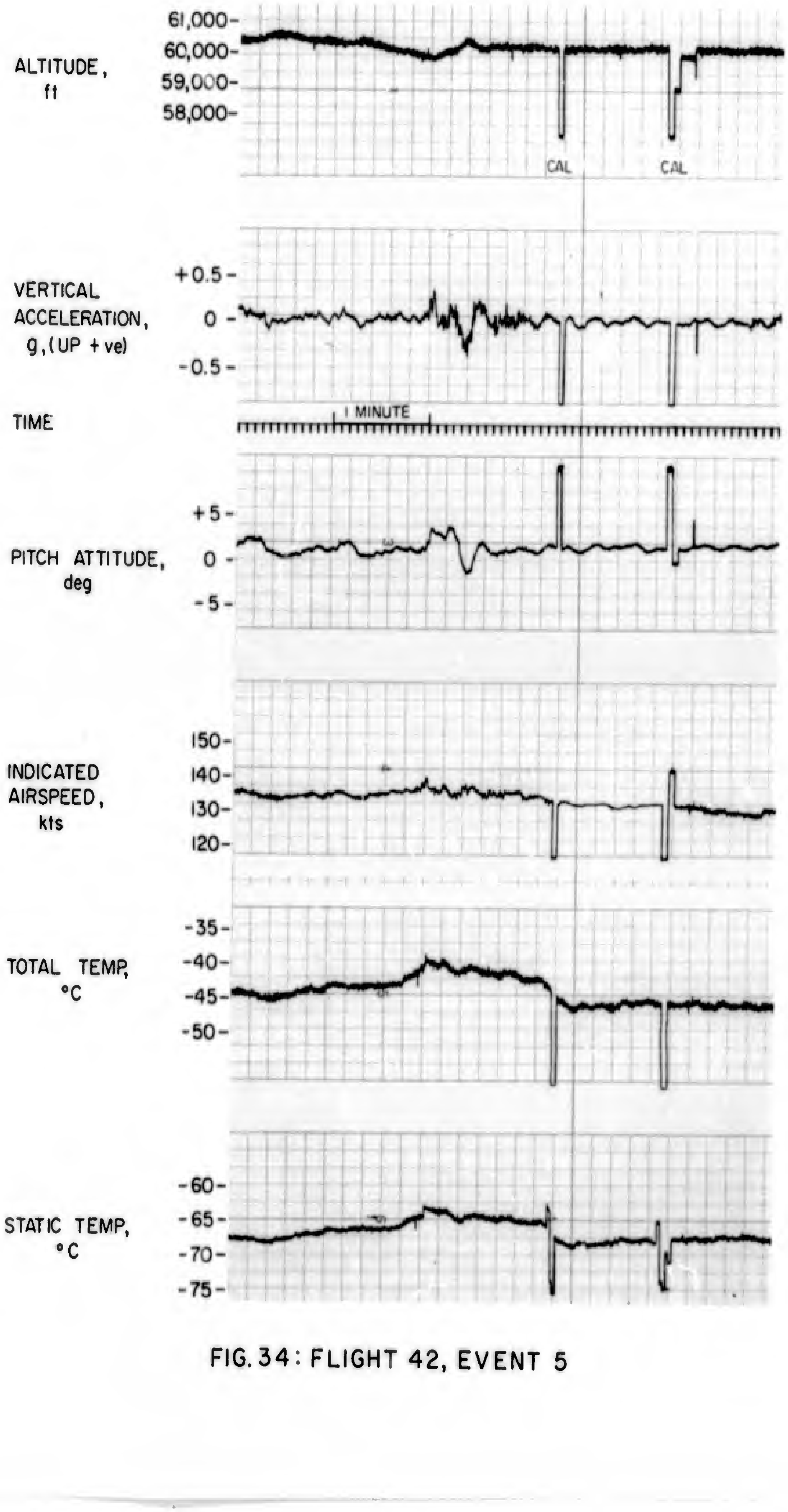


FIG. 34: FLIGHT 42, EVENT 5

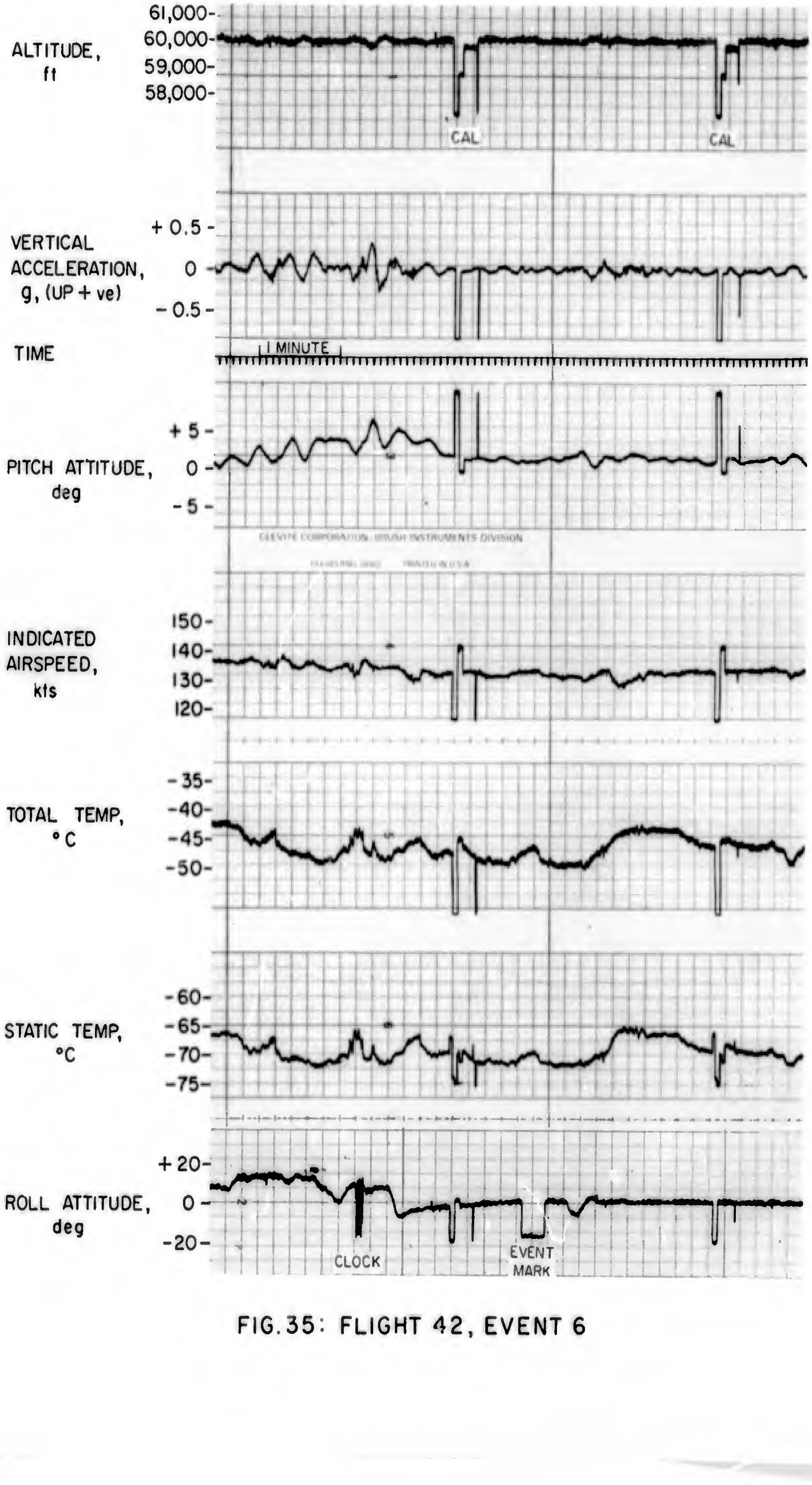


FIG. 35: FLIGHT 42, EVENT 6

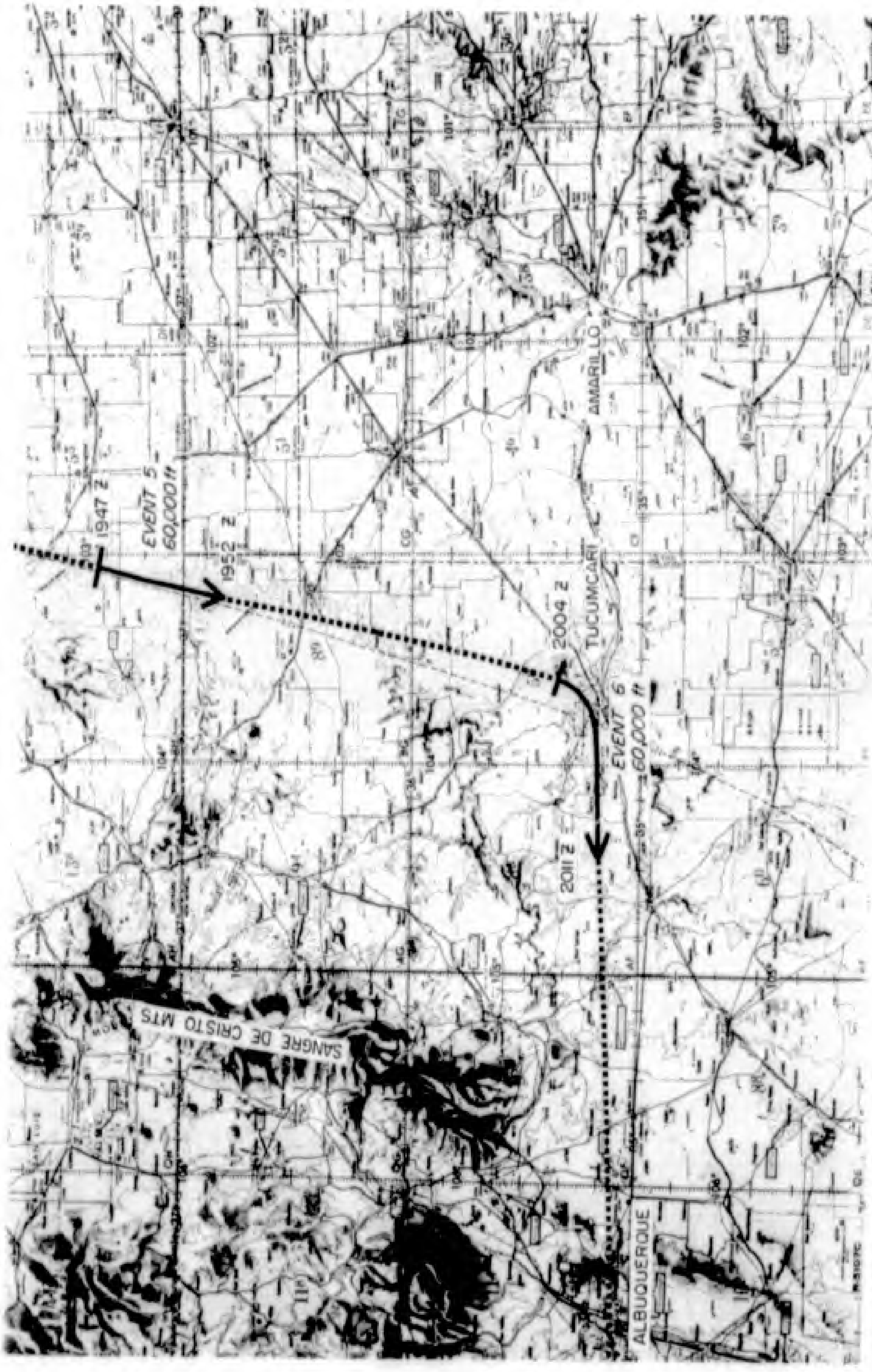


FIG.36: FLIGHT TRACK SHOWING EVENTS 5 AND 6 OF FLIGHT 42, 12 FEB 1970

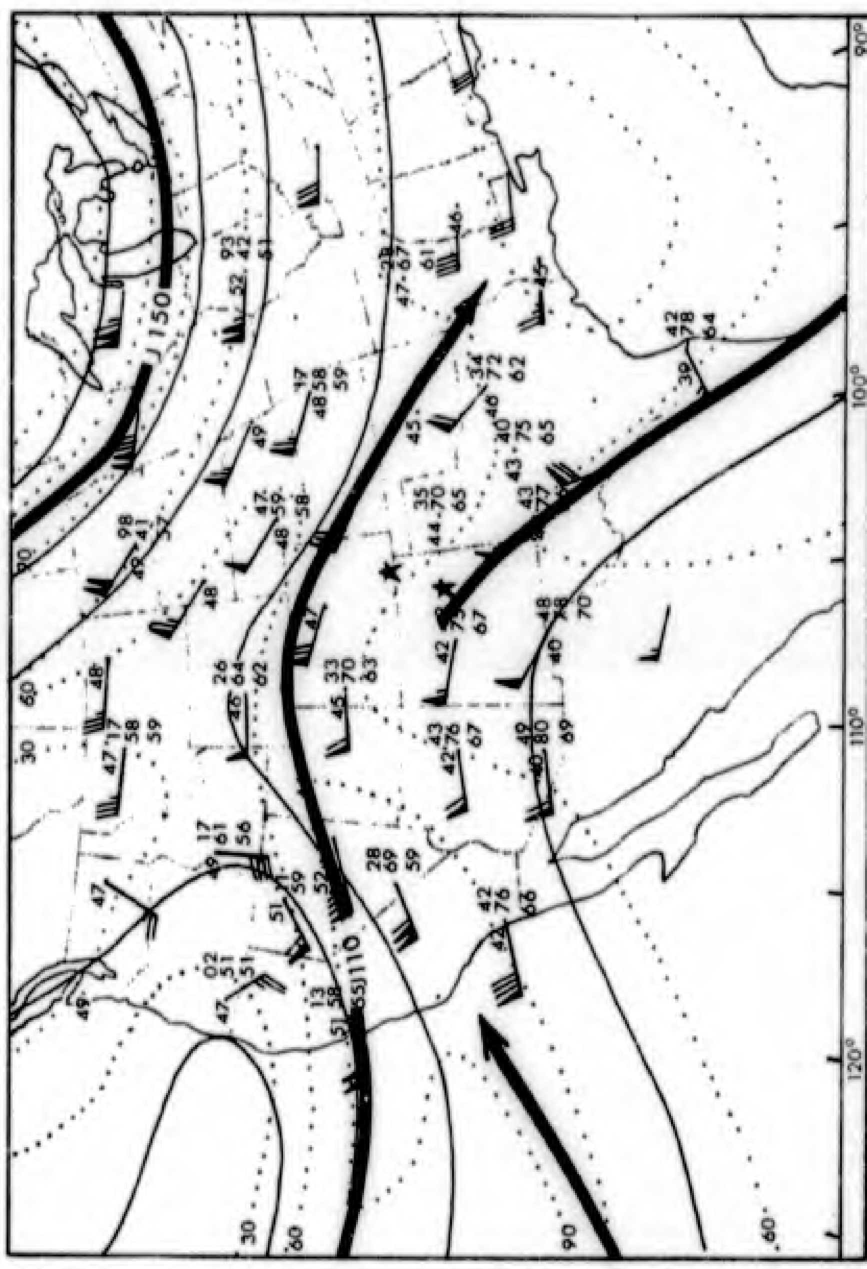


FIG. 37: 300-MB ANALYSIS, 0000 GMT, 13 FEB 1970

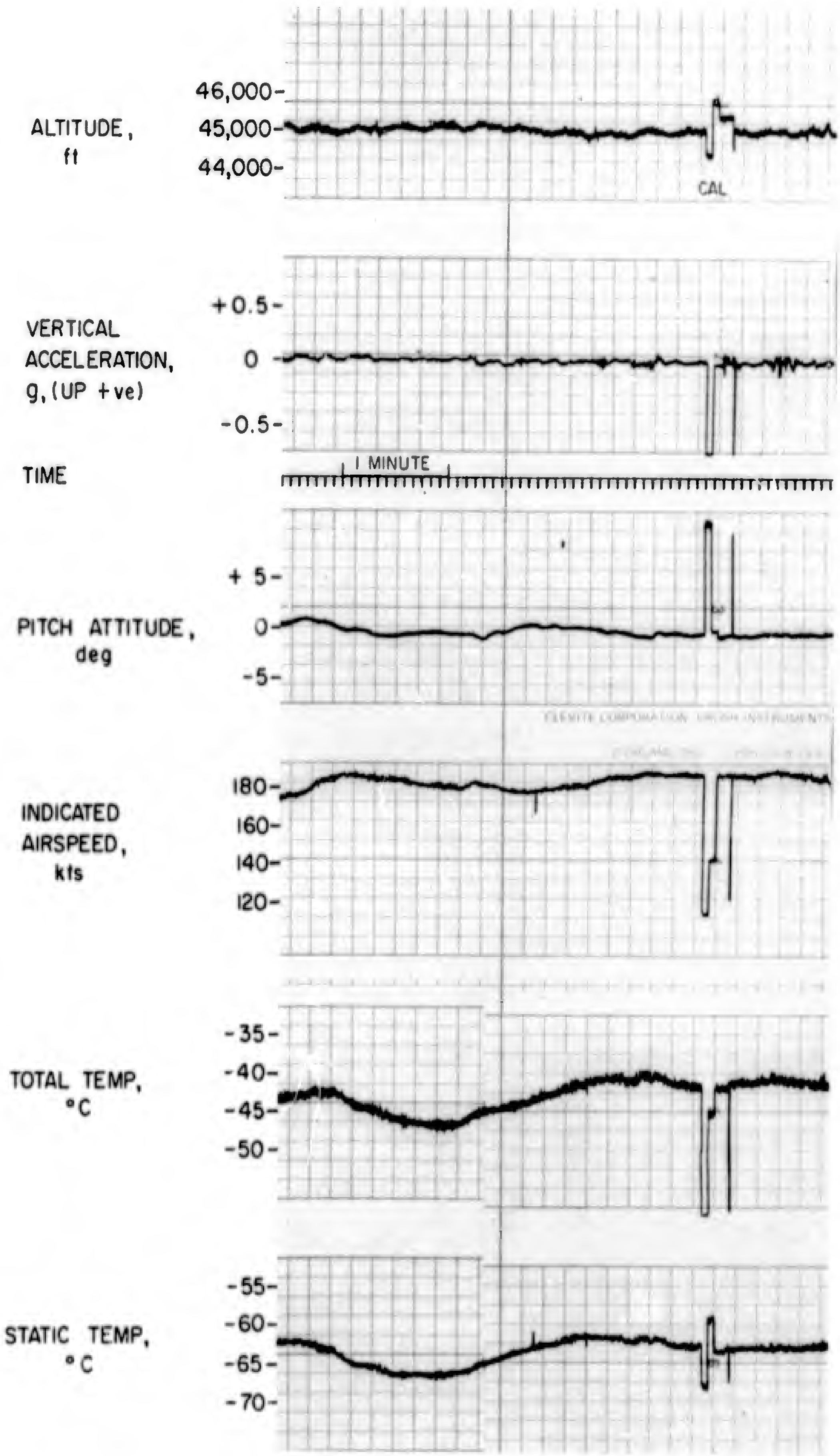


FIG. 38: FLIGHT 45, EVENT A

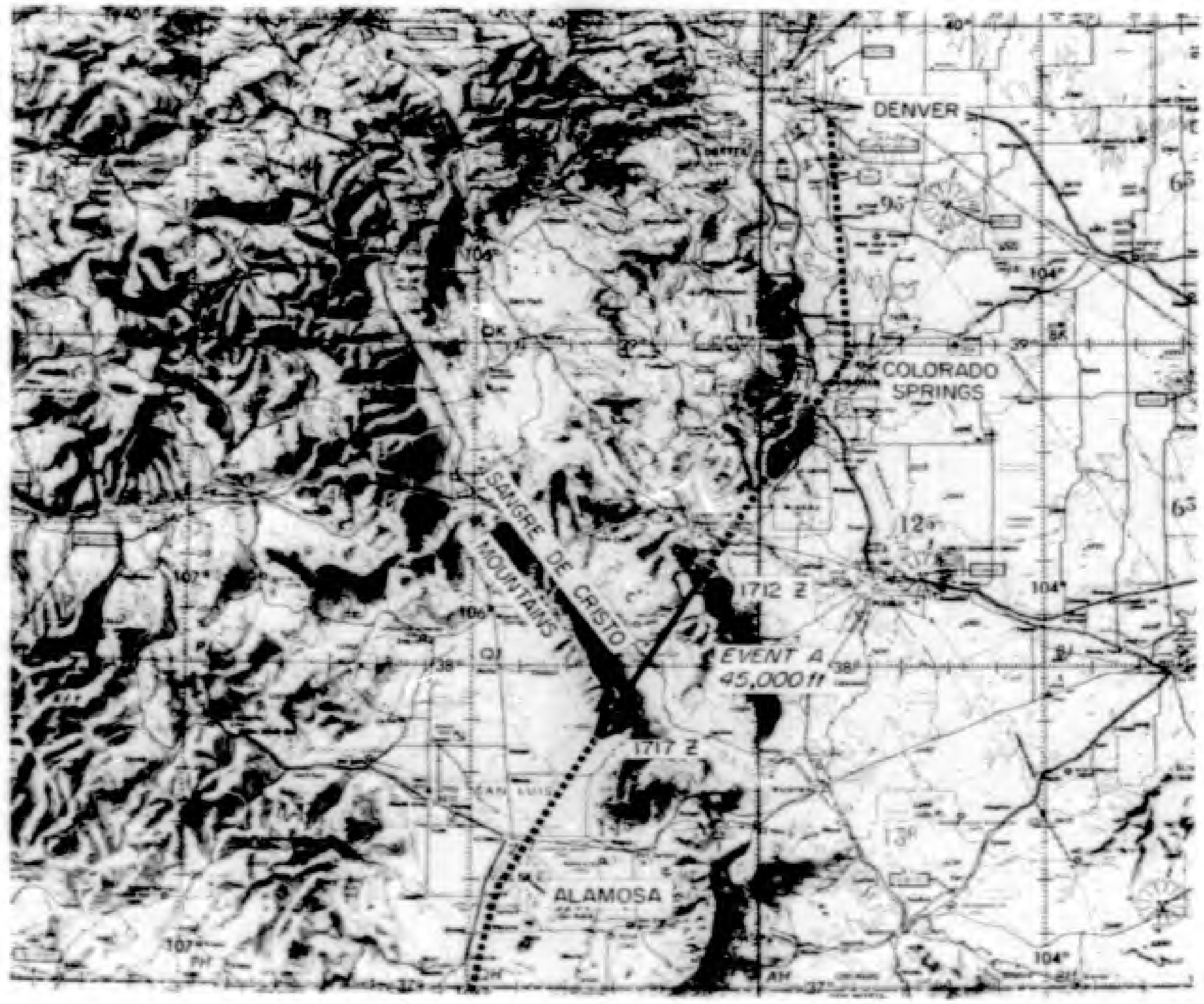


FIG.39: FLIGHT TRACK SHOWING EVENT A OF FLIGHT 45, 17 FEB 1970

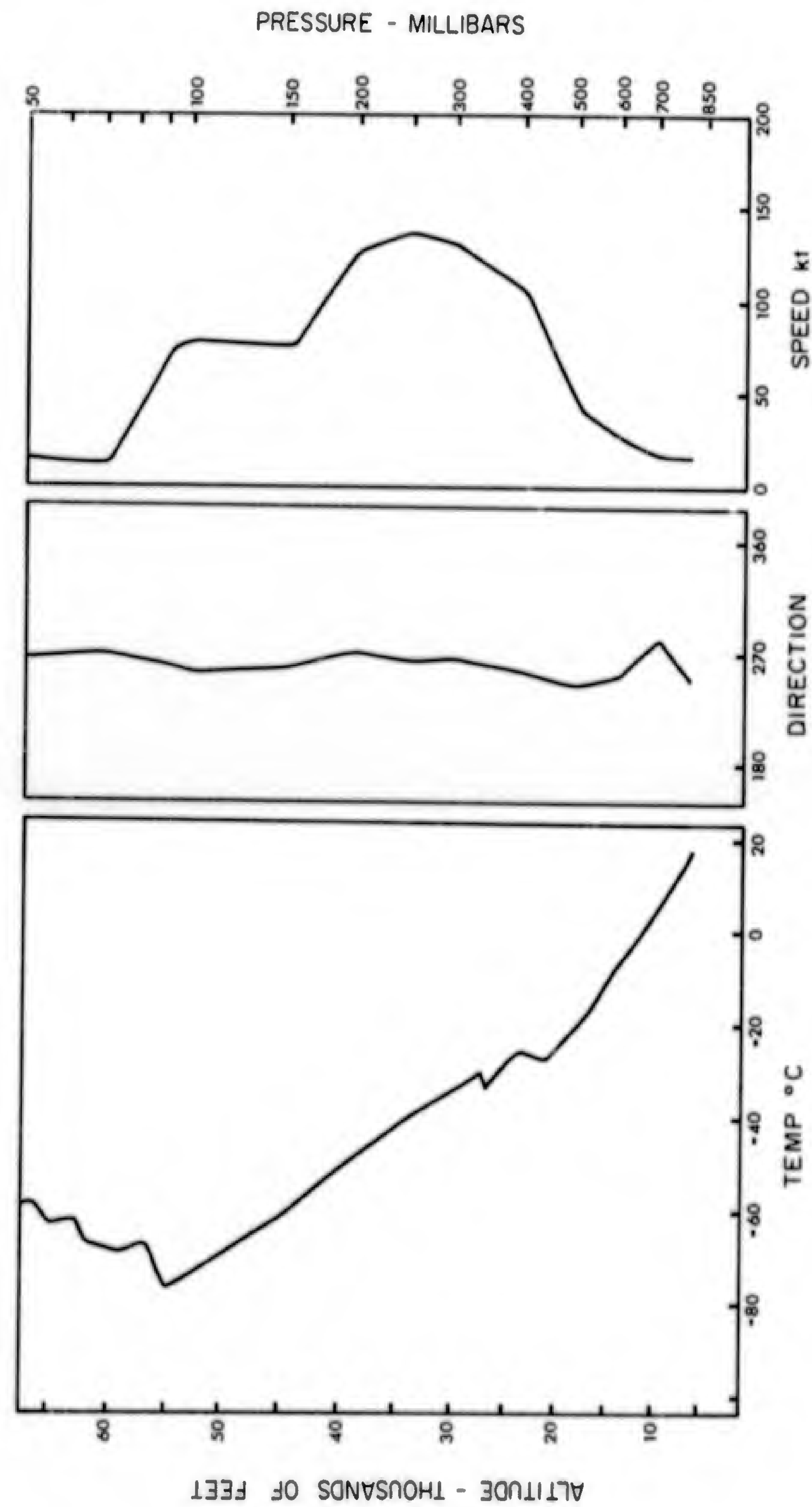


FIG. 40: UPPER AIR DATA

DENVER, COLORADO

0000 GMT 18 FEB 1970

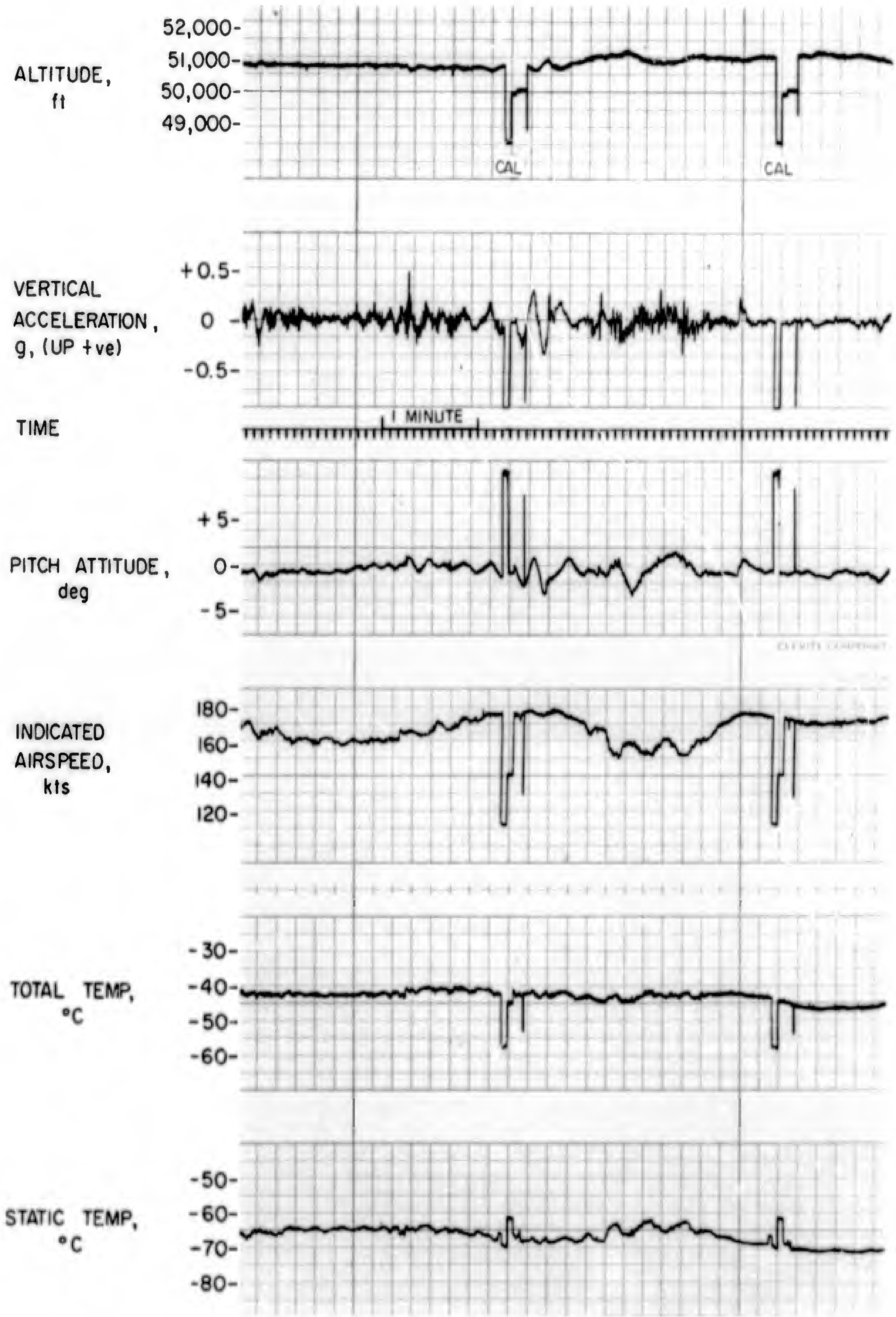


FIG. 41: FLIGHT 46, EVENT 1

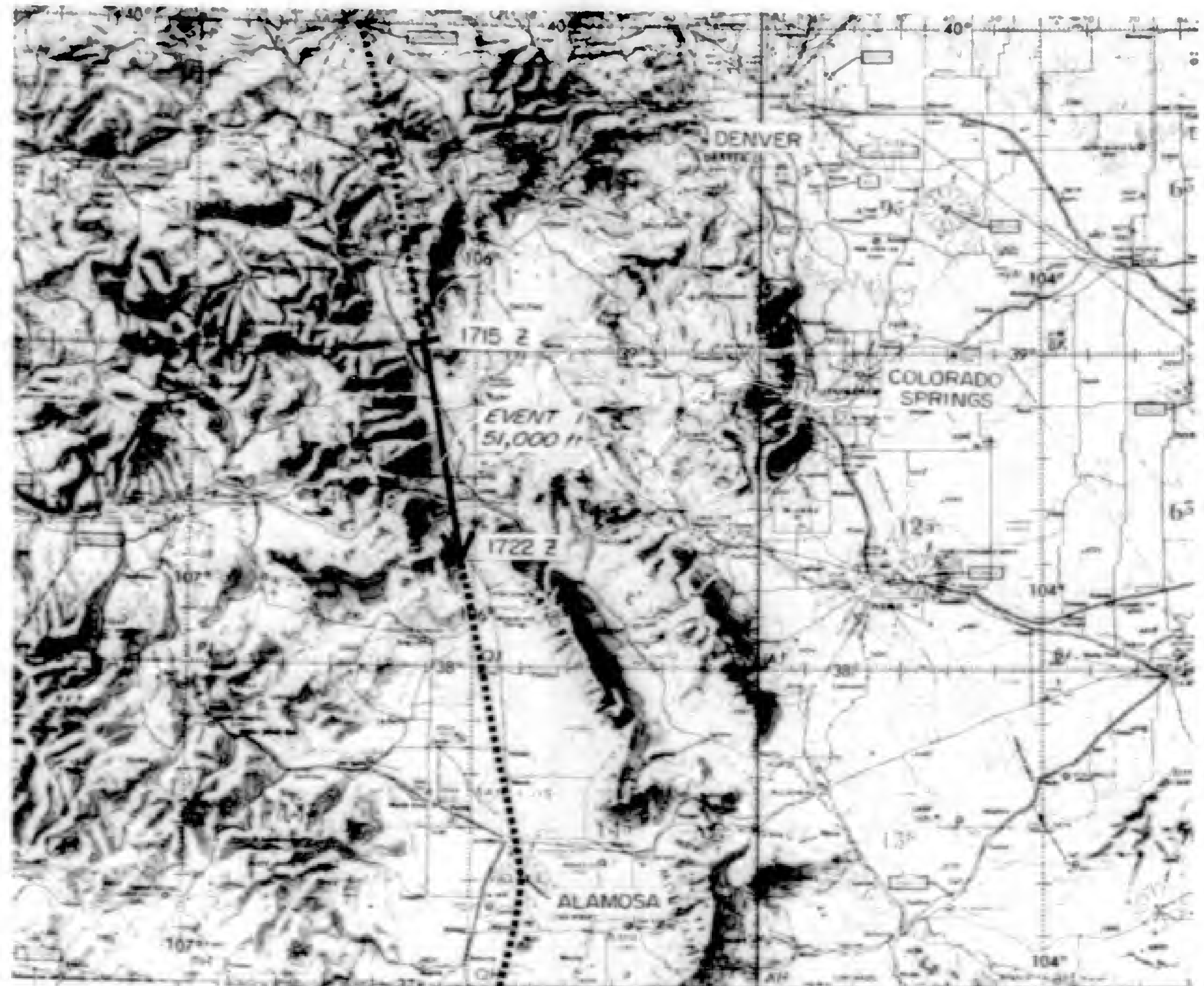


FIG. 42: FLIGHT TRACK SHOWING EVENT I OF FLIGHT 46, 18 FEB 1970

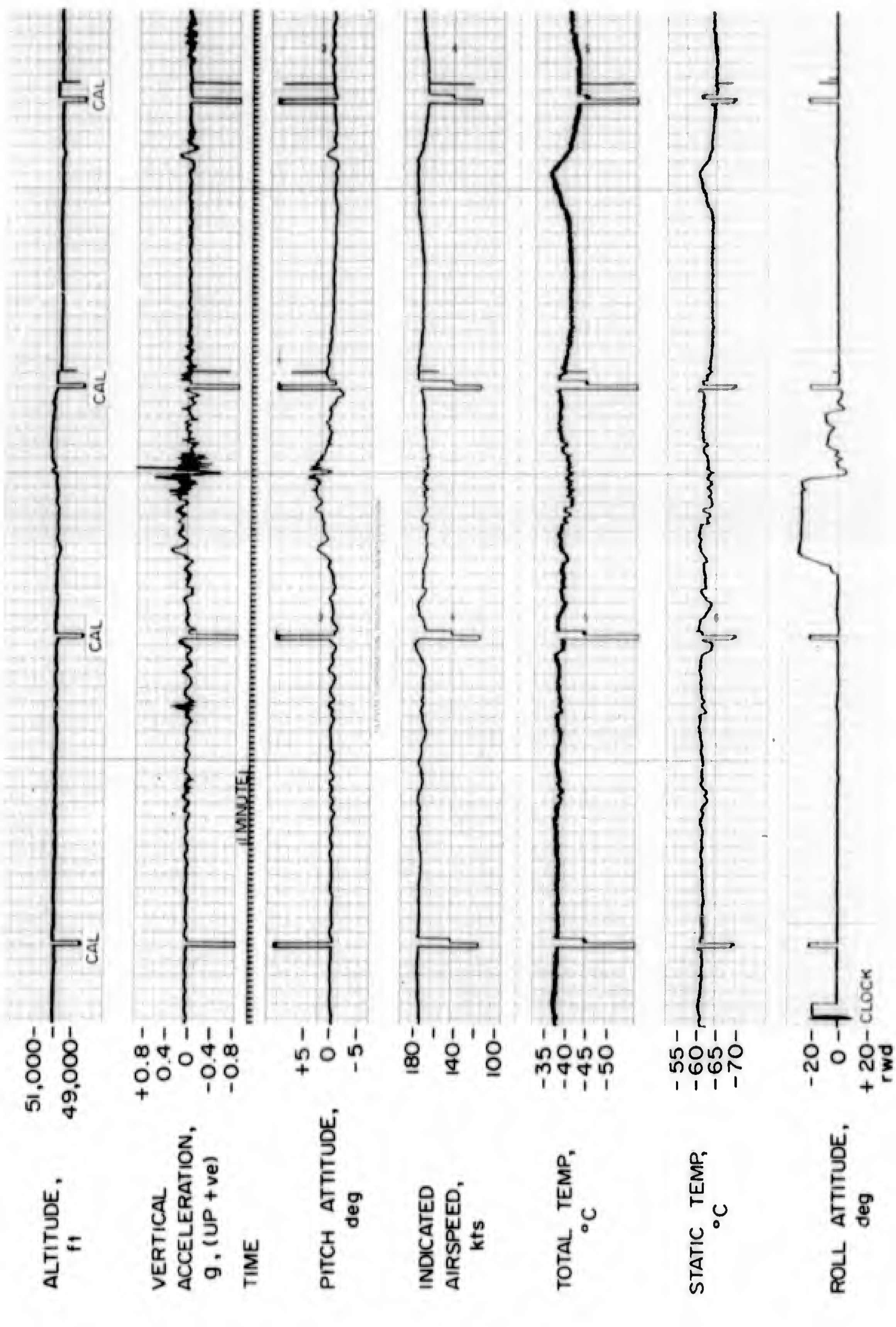


FIG. 43: FLIGHT 47, EVENT 3/4

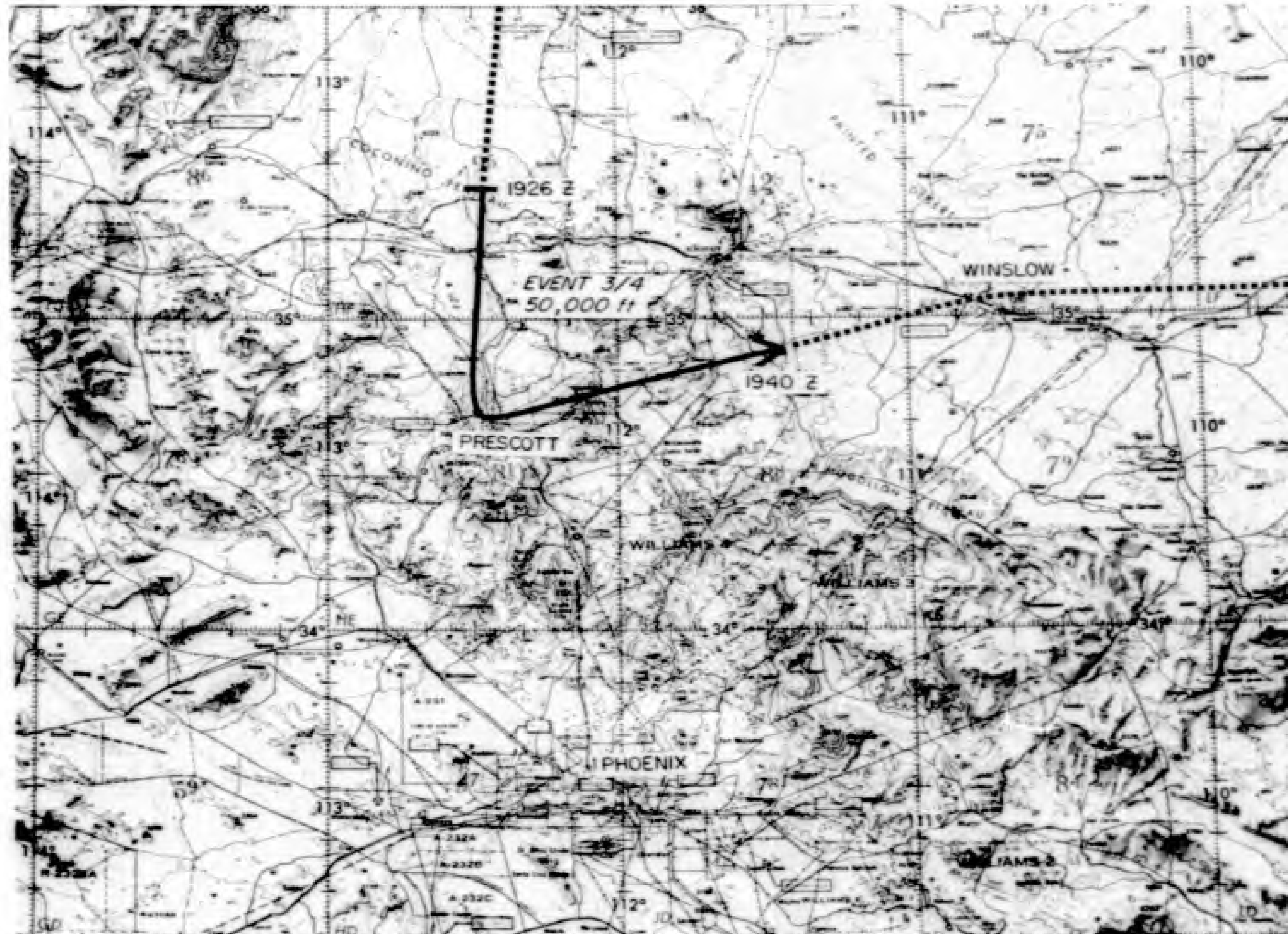


FIG. 44: FLIGHT TRACK SHOWING EVENT 3/4 OF FLIGHT 47, 20 FEB 1970

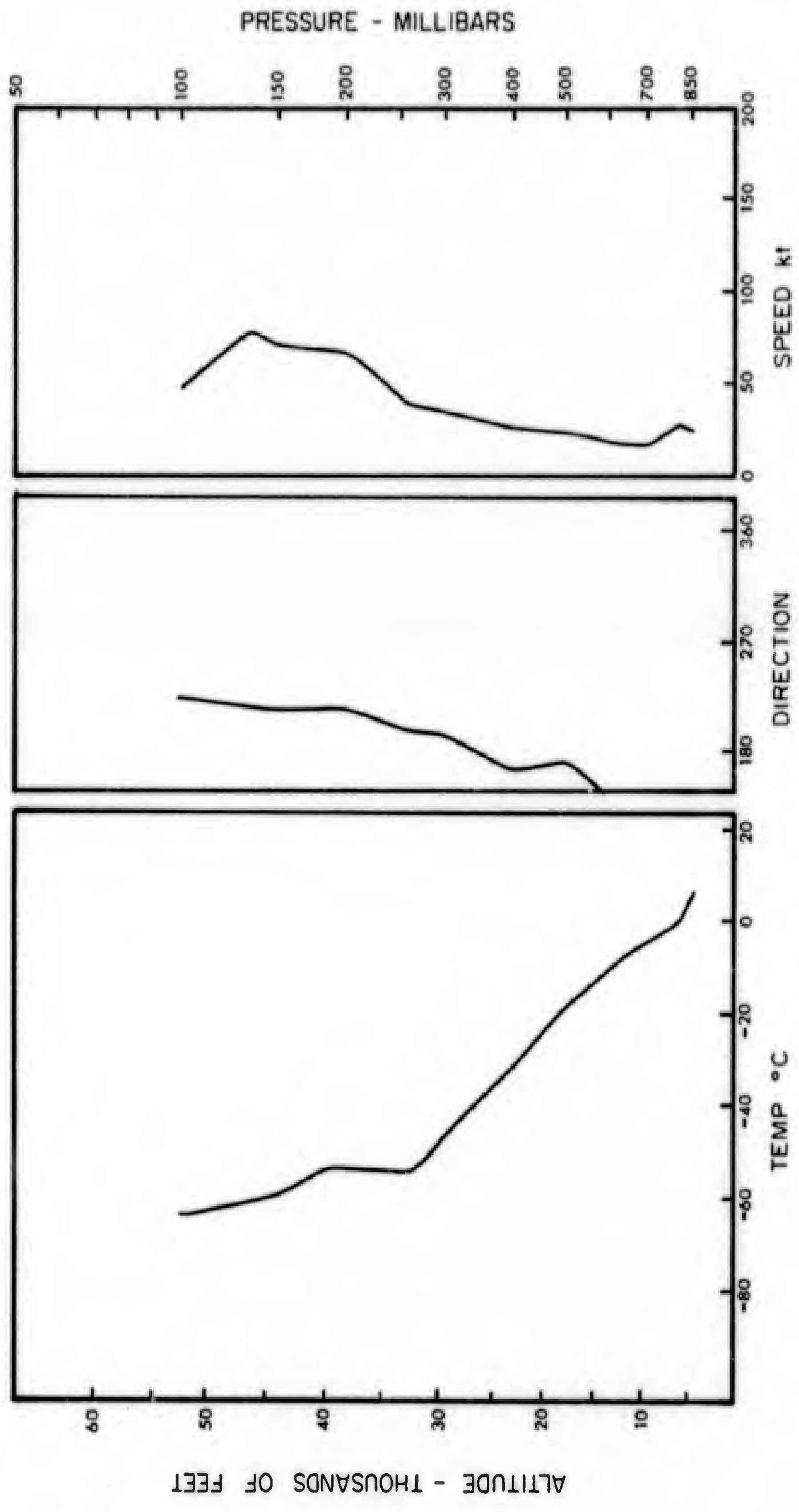


FIG. 45: UPPER AIR DATA

WINSLOW, ARIZONA

0000 GMT 21 FEB 1970

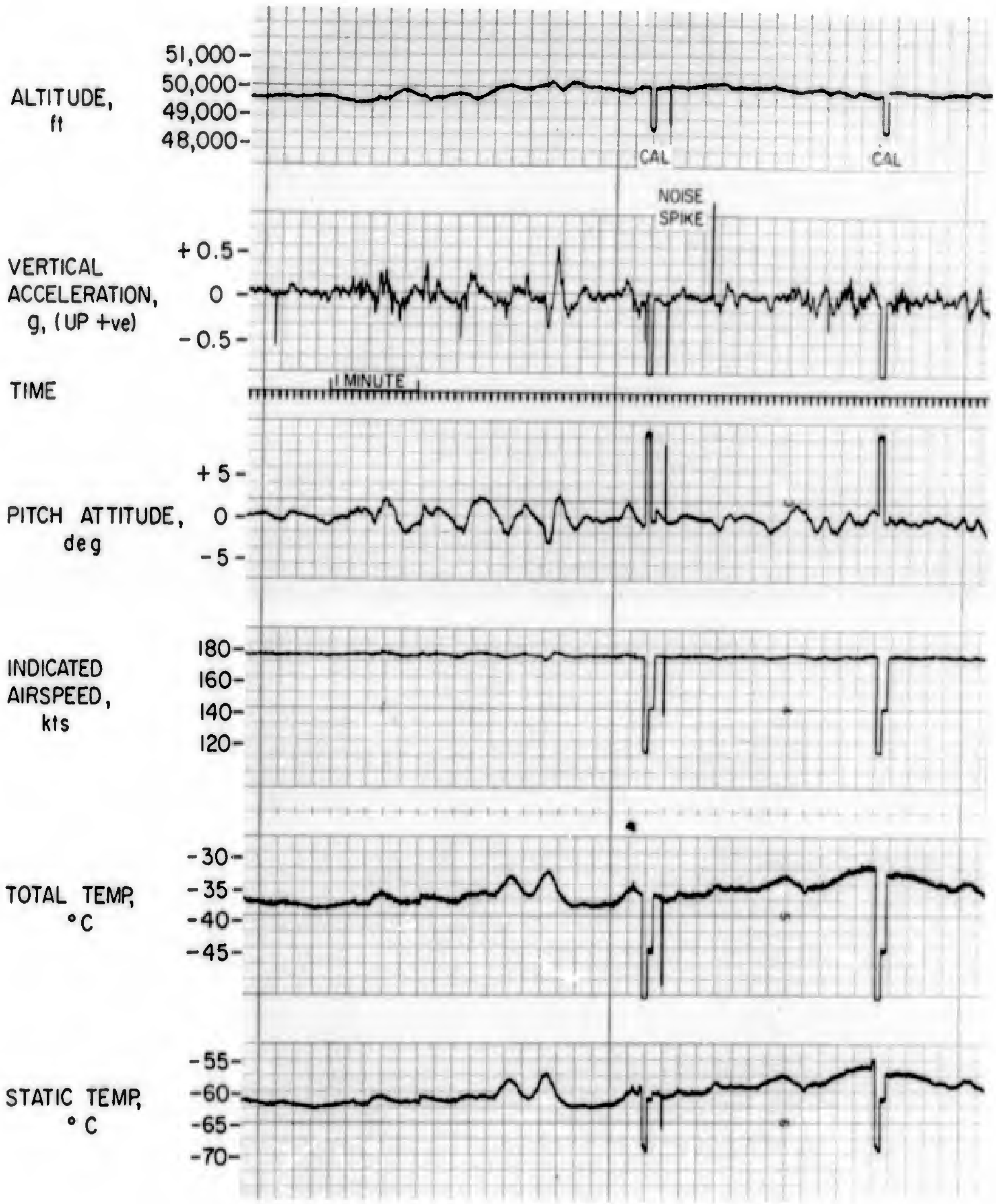


FIG.46: FLIGHT 51, EVENT 11

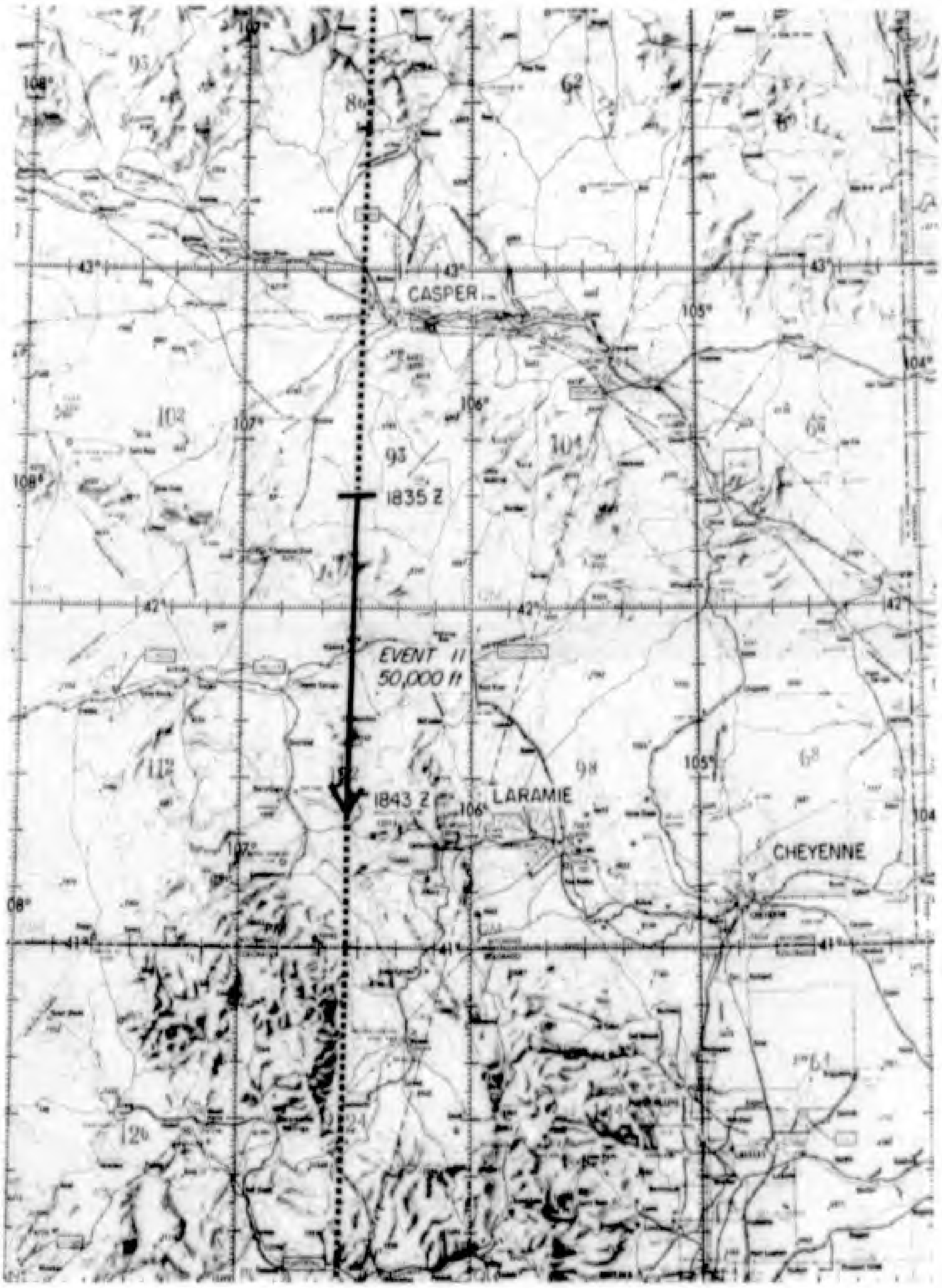


FIG. 47: FLIGHT TRACK SHOWING EVENT 11 OF FLIGHT 51, 27 FEB 1970

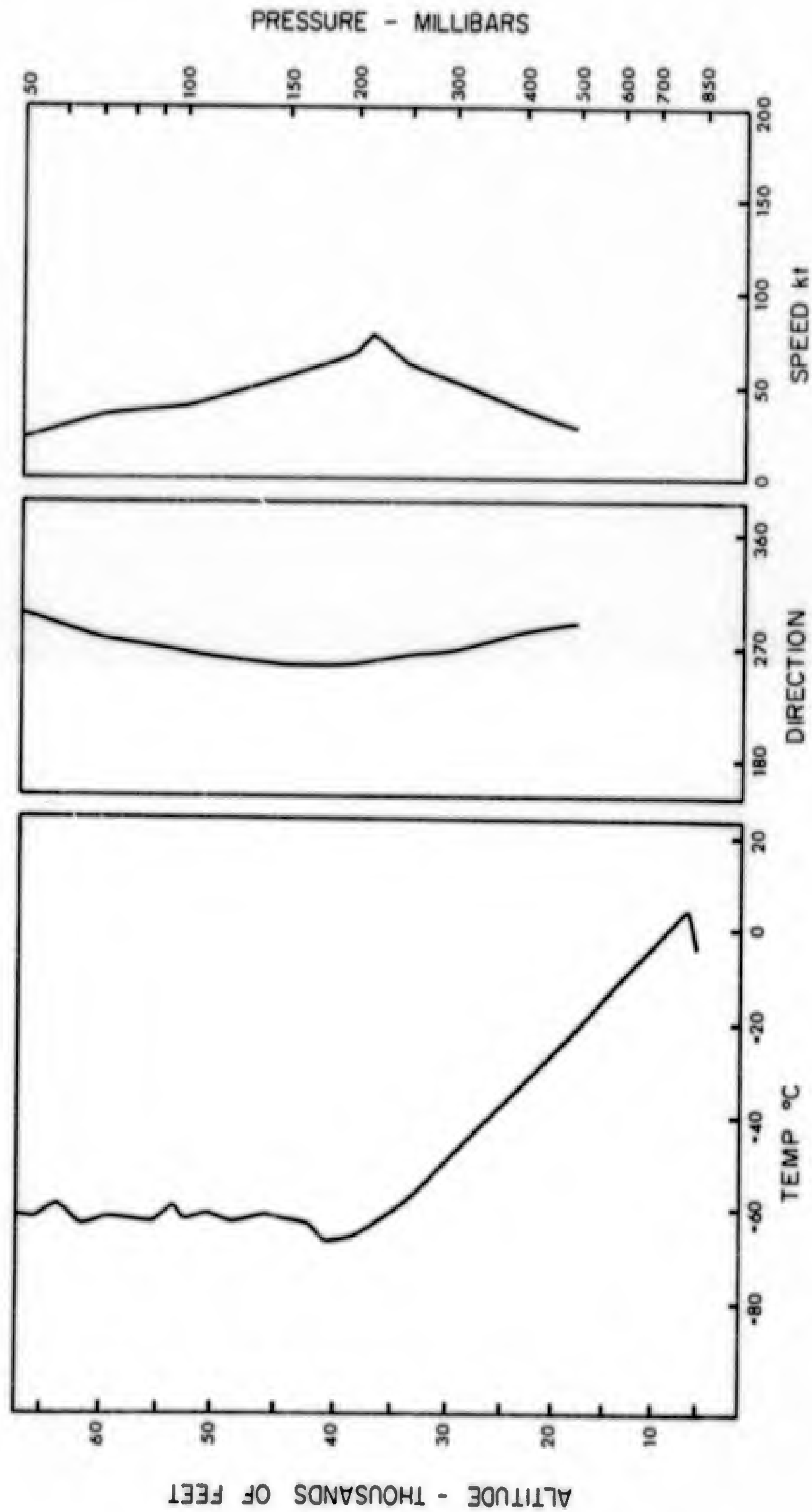


FIG. 48: UPPER AIR DATA

DENVER, COLORADO

1200 GMT 27 FEB 1970

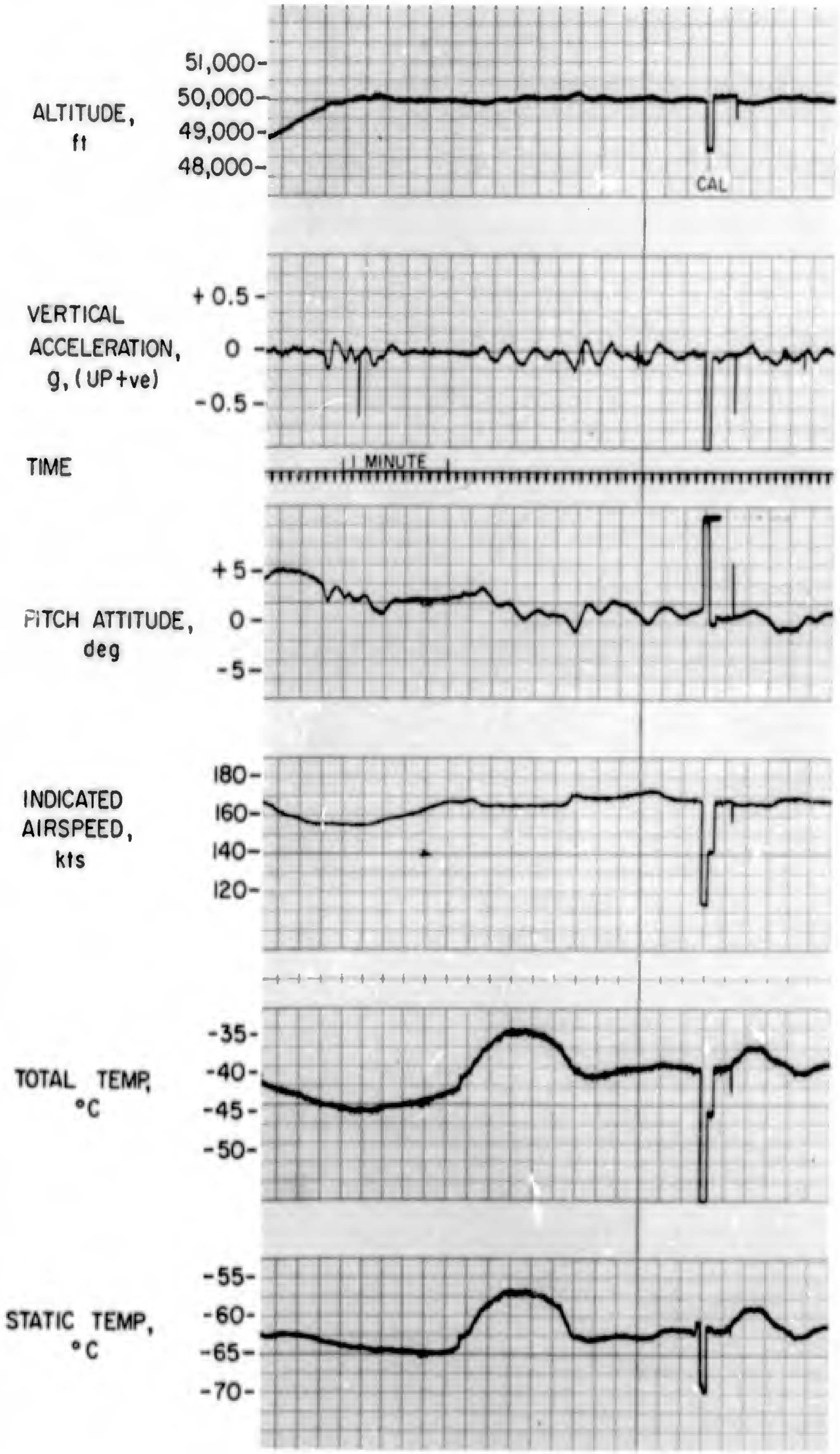


FIG. 49: FLIGHT 53, EVENT I

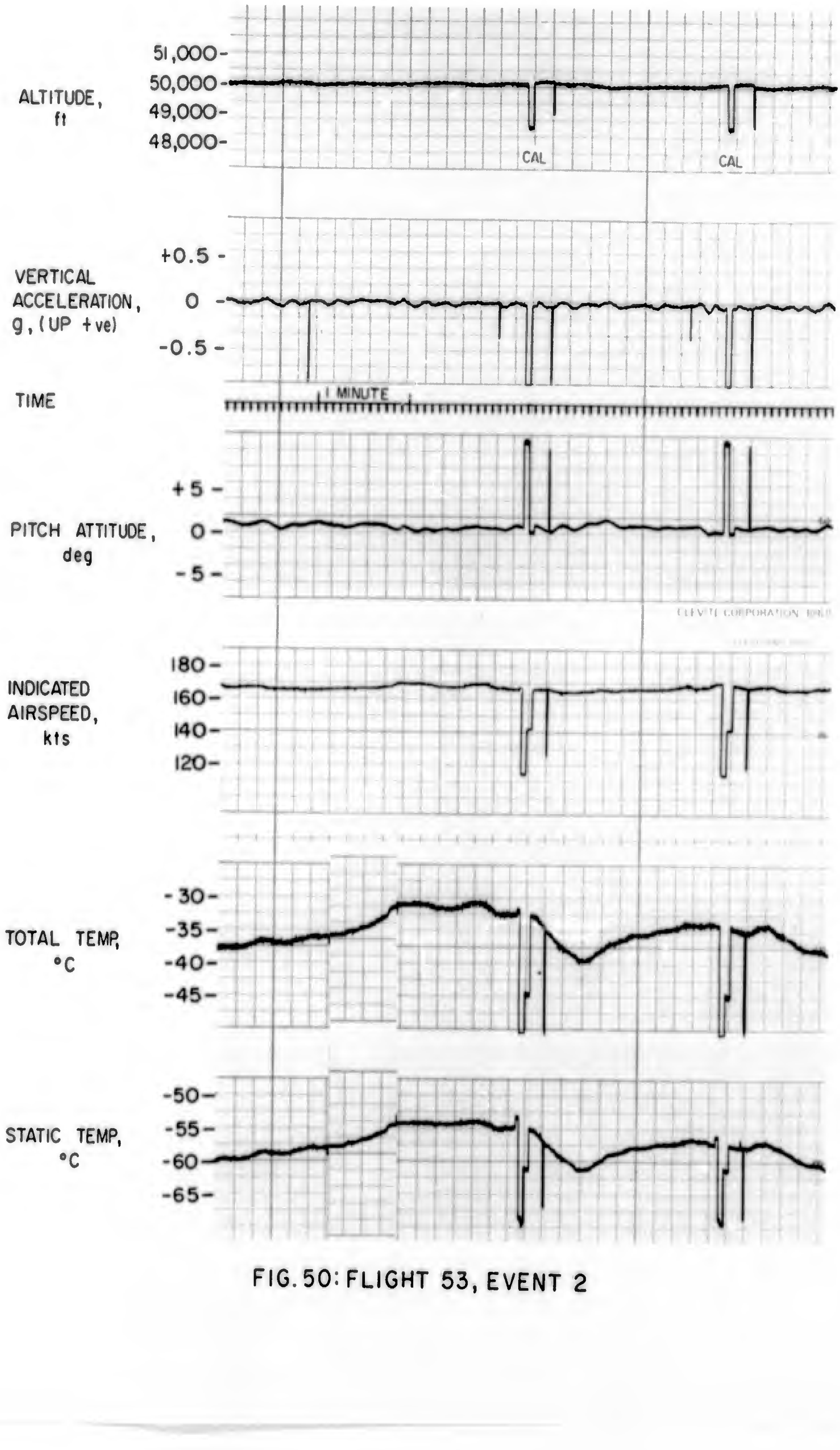


FIG. 50: FLIGHT 53, EVENT 2

FIG. 51: FLIGHT TRACK SHOWING EVENTS 1 AND 2 OF FLIGHT 53, 2 MARCH 1970

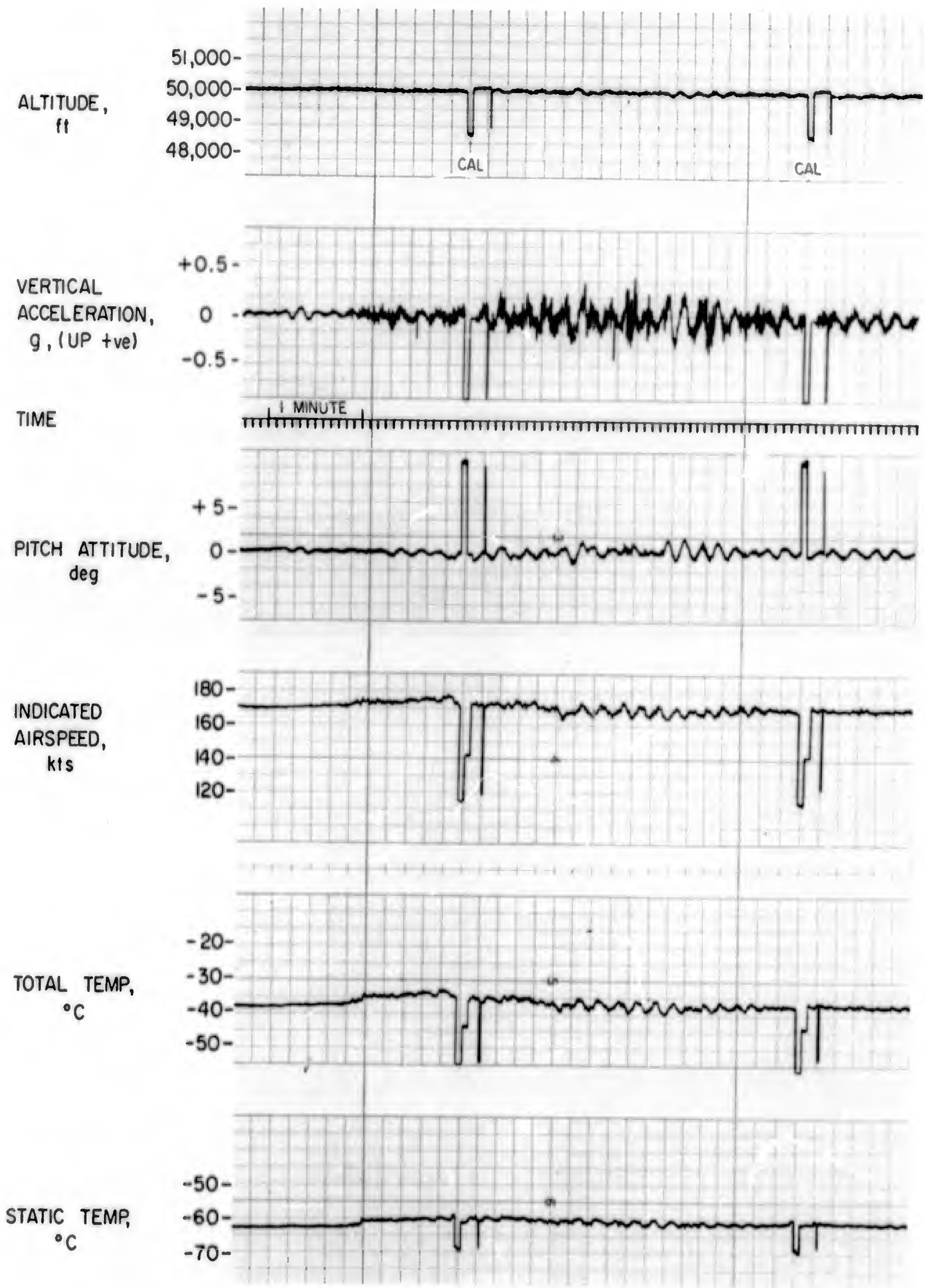


FIG. 52: FLIGHT 53, EVENT 4

FIG. 53: FLIGHT TRACK SHOWING EVENT 4 OF FLIGHT 53, 2 MARCH 1970

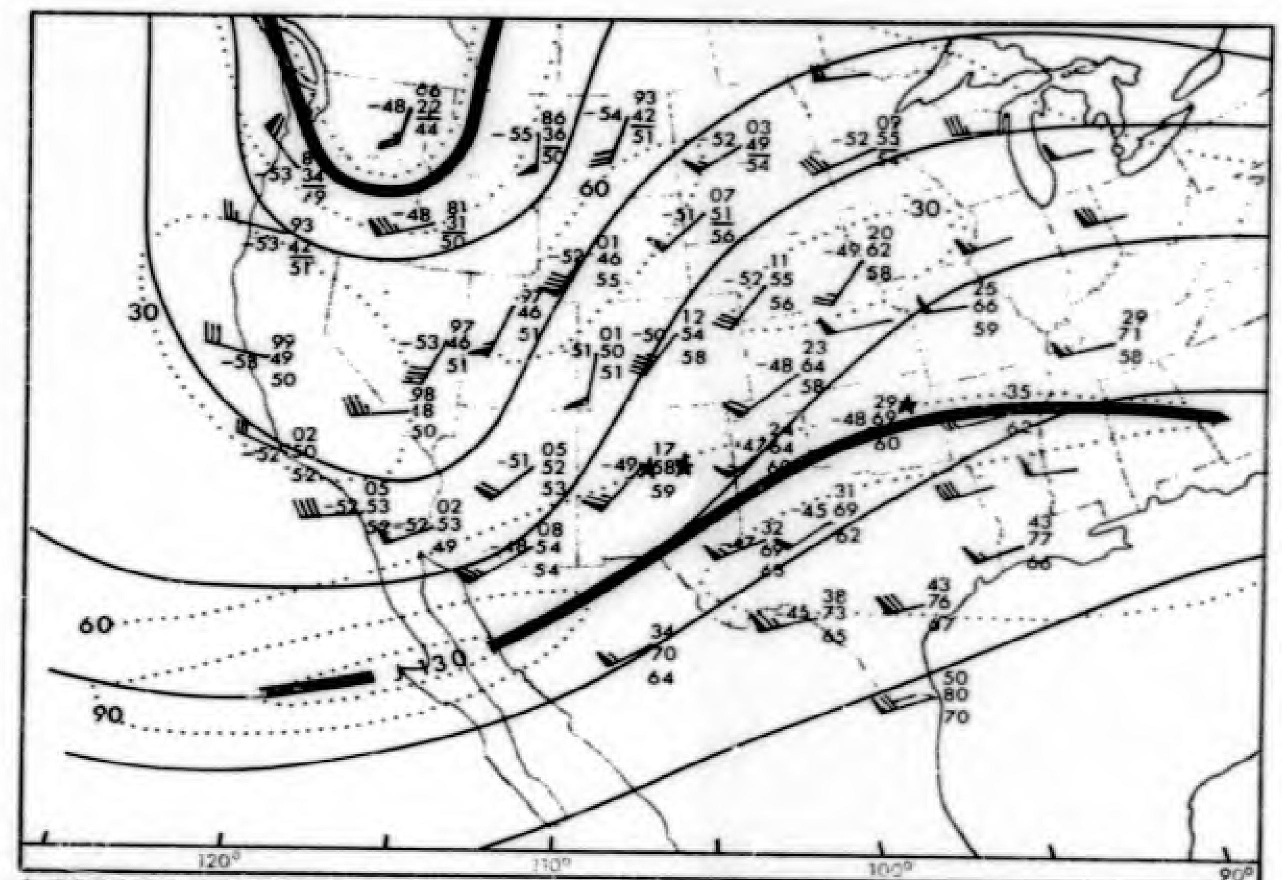


FIG.54: 300-MB ANALYSIS, 1200 GMT, 2 MARCH 1970

NRC, NAE LR-542
National Research Council of Canada. National Aeronautical Establishment.

STRATOSPHERIC TURBULENCE AND TEMPERATURE GRADIENTS MEASURED BY AN RE-57F. Coldscan Flights 19 to 56. J. I. MacPherson and E. G. Morrissey. November 1970.
80 pp (incl. tab. and figs.)

Since January 1969, a USAF RB-57F high altitude weather reconnaissance aircraft has carried a special NRC instrumentation system to measure and record stratospheric turbulence and horizontal temperature gradients encountered at altitudes from 40,000 to above 60,000 feet. The chief purpose of this co-operative program, named "Coldscan", is to collect data on atmospheric conditions at altitudes to be flown by the supersonic transports. To date, 57 data flights have been flown, covering 82,000 nautical miles of the central and western United States, Ontario, and the Pacific Ocean south of Panama. This is the second Coldscan data report and includes a summary of the results of all 57 flights, in addition to detailed accounts of a selection of 20 events from Flights 19 through 56 that showed significant temperature gradients or light to moderate turbulence. These presentations include time histories of the recorded variables, flight tracks showing event positions, and meteorological analyses. Data are presented on the correlation between measured stratospheric turbulence and horizontal temperature gradients, on the altitude and geographical distribution of the turbulence and temperature change encounters, and on the positions of the recorded incidents relative to the jet stream.

UNCLASSIFIED

1. Clear air turbulence
2. Stratosphere- Turbulence
3. Coldscan (Project)
4. Aircraft (General Dynamics/ Martin 57F)
5. Aircraft (Supersonic)

I. MacPherson, J. I.
II. Morrissey, E. G.
III. NRC, NAE LR-542

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