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INFLIGHT DATA COLLECTION FOR RIDE QUALITY AND ATMOSPHERIC TURBULENCE RESEARCH

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16. Abstract

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Data were collected on a series of 57 flights on a Boeing 747 over the Chicago, Illinois-Los Angeles, California and Los Angeles-Honolulu, Hawaii routes. Atmospheric and aircraft performance data obtained from special sensors, as well as conventional instruments and avionics systems normally available on the B-747, were collected on a special flight recorder. In addition, qualified scientific observers participated in the flight program to manually record visual observations of meteorological conditions encountered enroute together with supplemental aircraft performance data.

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SUMMARY

In 1971, Continental Airlines and the National Center for Atmospheric Research (NCAR) originated a joint program to study the genesis and nature of clear air turbulence. With the support of the National Aeronautics and Space Administration (NASA) Flight Research Center, the program was expanded to include an investigation of the effects of atmospheric turbulence on passenger ride quality in a large wide-body commercial aircraft.

Data were collected on a series of 57 flights on a Boeing 747 over the Chicago, Illinois-Los Angeles, California and Los Angeles-Honolulu, Hawaii routes. Atmospheric and aircraft performance data obtained from special sensors, as well as conventional instruments and avionics systems normally available on the B-747, were collected on a special flight recorder. In addition, qualified scientific observers participated in the flight program to manually record visual observations of meteorological conditions encountered enroute together with supplemental aircraft performance data.

The major objective of the program was to record inflight data and prepare it for detailed analysis by the Flight Research Center in conjunction with its ride quality research study. In support of this objective, additional instrumentation including a Universal Indicated Turbulence System (UITS) and two tail-mounted single axis accelerometers were installed in the B-747 to measure aircraft response to atmospheric motions. Furthermore, qualified NASA observers rode in the rear of the passenger cabin of the aircraft to make subjective evaluations of ride quality inflight. This information was then transmitted to the special flight recorder.

Data from the flight recorder were reduced by the Computer Center at NCAR and reformatted into computer tapes. Copies of the computer tapes were sent to the Flight Research Center for detailed study in conjunction with the ride quality program.

Preliminary analysis of the aircraft and atmospheric data indicates that the research program has provided information which may contribute knowledge related to the genesis and nature of atmospheric motions that affect an aircraft and occupants during flight.

INTRODUCTION

During the past 20 years, research by numerous organizations has been directed towards investigating the formation and life cycle of clear air turbulence (CAT) and its effect on an aircraft in flight. Continental Airlines (CAL) and the National Center for Atmospheric Research (NCAR) originated a joint research program in 1971 to contribute knowledge to this study. The purpose of this program was to collect atmospheric and aircraft performance data on a specially instrumented Boeing 747 that would provide both large and microscale atmospheric information relating to the genesis and nature of CAT. The data were to be ultimately utilized in the development of improved forecasting techniques and design of a practical airborne CAT detection system.

At the same time, the National Aeronautics and Space Administration (NASA) Flight Research Center initiated a program to study the effects of atmospheric turbulence on passenger ride quality in various types of aircraft. The program utilized an airborne simulator that was installed in a specially instrumented small corporate jet. This system could simulate inflight response and handling characteristics of several types of aircraft from general aviation to supersonic transports. Since both the CAL-NCAR and Flight Research Center programs required nearly identical aircraft instrumentation and equipment for collecting flight data, it became apparent that a joint effort to combine both programs would be mutually beneficial. Therefore, with the support of the Flight Research Center, the CAL-NCAR program was expanded to include an investigation of the effects of atmospheric turbulence on passenger ride quality in a large wide-body commercial jet aircraft.

Before the initial flight of the data collection program, additional special sensors and equipment were added to the standard instrumentation of the B-747 to fulfill the purpose and objectives associated with both the original CAL-NCAR program and the Flight Research Center sponsored study. Merging the NASA program with the CAL-NCAR study resulted in a complete one-time engineering, procurement, installation, and certification effort that was highly cost effective. Each of the participants in the combined program contributed special instrumentation from its own resources. The Flight Research Center provided the following equipment:

1. A Meteorology Research, Inc., Univeral Indicated Turbulence System (UITS) and a separate Rosemount pitot-static sensor to provide an objective measurement of turbulence by sensing variations in airspeed.

2. Two tail-mounted single axis accelerometers to measure lateral and vertical accelerations in the rear of the airplane.

3. A portable ride quality rating box for use by qualified NASA observers to subjectively evaluate ride quality on each data collection flight.

The following equipment was provided by The National Center for Atmospheric Research:

1. A Sangamo, Model 3561, Portable Recorder/Reproducer and power supply to record all inflight data.

2. A Signal Conditioning Unit and Airborne Recording and Instrumentation System (ARIS) to provide the interface between all aircraft sensors and systems and the Sangamo recorder.

3. A special airfoil shaped pylon mounted on top of the aircraft which was designed to hold an infrared sensor.

Continental Airlines provided the Boeing 747 in which the sensors and equipment were installed as well as the following:

1. A fast response Rosemount total temperature sensor to measure temperature changes encountered in flight.

2. A Rockwell International Autonetics Division infrared sensor to measure temperature changes by sensing the temperature of carbon dioxide (CO_2), hence the atmosphere. The sensor was consigned to CAL by Rockwell International for this program.

3. Wiring harnesses between all special sensors and systems and the Sangamo Recorder.

Other instruments already available on the B-747 included a Litton, LTN-51 Inertial Navigation System (INS), Bendix Central Air Data Computer (CADC) and a Teledyne Expandable Flight Data Acquisition and Recording System (EFDARS).

In addition to the data collected on the Sangamo recorder, qualified scientific observers riding in the cockpit participated in the flight program. It was their responsibility to operate the Sangamo recorder and manually record visual observations of meteorological conditions encountered enroute together with supplemental aircraft performance data. The Flight Research Center also provided trained subject passengers to conduct an evaluation of ride quality on each flight. A special seat in the last row of the passenger cabin was assigned to the observer and fitted with a wiring harness and connector. On each flight, the NASA observer carried a portable rating box that was connected to the wiring harness. The observer passenger continuously evaluated the ride quality and categorized his impressions according to a pre-determined five digit numerical scale with each number assigned to a push button on the rating box. By depressing the appropriate push button, the observer's evaluation of ride quality was transmitted as an output signal from the rating box to the Sangamo recorder in the cockpit.

Installation of all sensors, equipment and associated wiring was completed on June 11, 1973 by Continental Airlines in Los Angeles. Final approval and certification by the Federal Aviation Administration for work accomplished on this program was received after the successful completion of a test flight on June 12, 1973. Data collection began on September 28, 1973 and was terminated on January 10, 1974 with the completion of 57 flights.

The Boeing 747 flew regular scheduled commercial flights carrying passengers and cargo on the Chicago - Los Angeles - Honolulu route exclusively. The aircraft was never purposefully flown into a known or forecast turbulent area. In other words, all turbulence encountered in the data collection program occurred during normal flight operations in which safety and passenger comfort were the primary considerations.

DATA COLLECTION EQUIPMENT AND INSTRUMENTATION

The data collection equipment for the ride quality/turbulence program consisted of special sensors, signal conditioning and interfacing units, a special flight recorder and on-board avionics systems of the B-747 aircraft. Figure 1 is a block diagram of the complete system. The outputs from each subsystem are indicated by the directional flow paths. Digital signals from the special sensors were transmitted directly to the Signal Conditioning Unit. Analog signals from the aircraft avionics systems were routed initially to the Flight Data Acquisition Unit (FDAU) and converted to a digital output for transmission to the Signal Conditioning Unit. The Signal Conditioning Unit and Airborne Recording Instrumentation System (ARIS) provided the interface between the output of all sensors and systems and the special flight recorder. In addition, a remote indicator panel enabled the meteorologist observer to monitor the output of three of the special sensors in real time.

Outputs from the various sensors and systems were sampled at different rates depending on the data analog requirements. The sampling rates varied from 64 per second for the single axis vertical and lateral tail-mounted accelerometers and the infrared sensor down to .5 per second for coarse altitude and Mach number outputs from the Central Air Data Computer. A block diagram indicating the parameters received from each subsystem and their respective sampling rates is shown in Figure 2.

Tape Recorder and Power Supply

A Sangamo, Model 3561, Portable Recorder/Reproducer was used for recording all the inflight data. This fast response magnetic tape instrumentation system provided tape recording speeds of 30, 15, 7½, 3 3/4, 1 7/8, and 15/16 ips with a normal FM frequency response to 10 KHZ at 30 ips. An optimum tape speed of 3 3/4 ips was selected for recording data on all

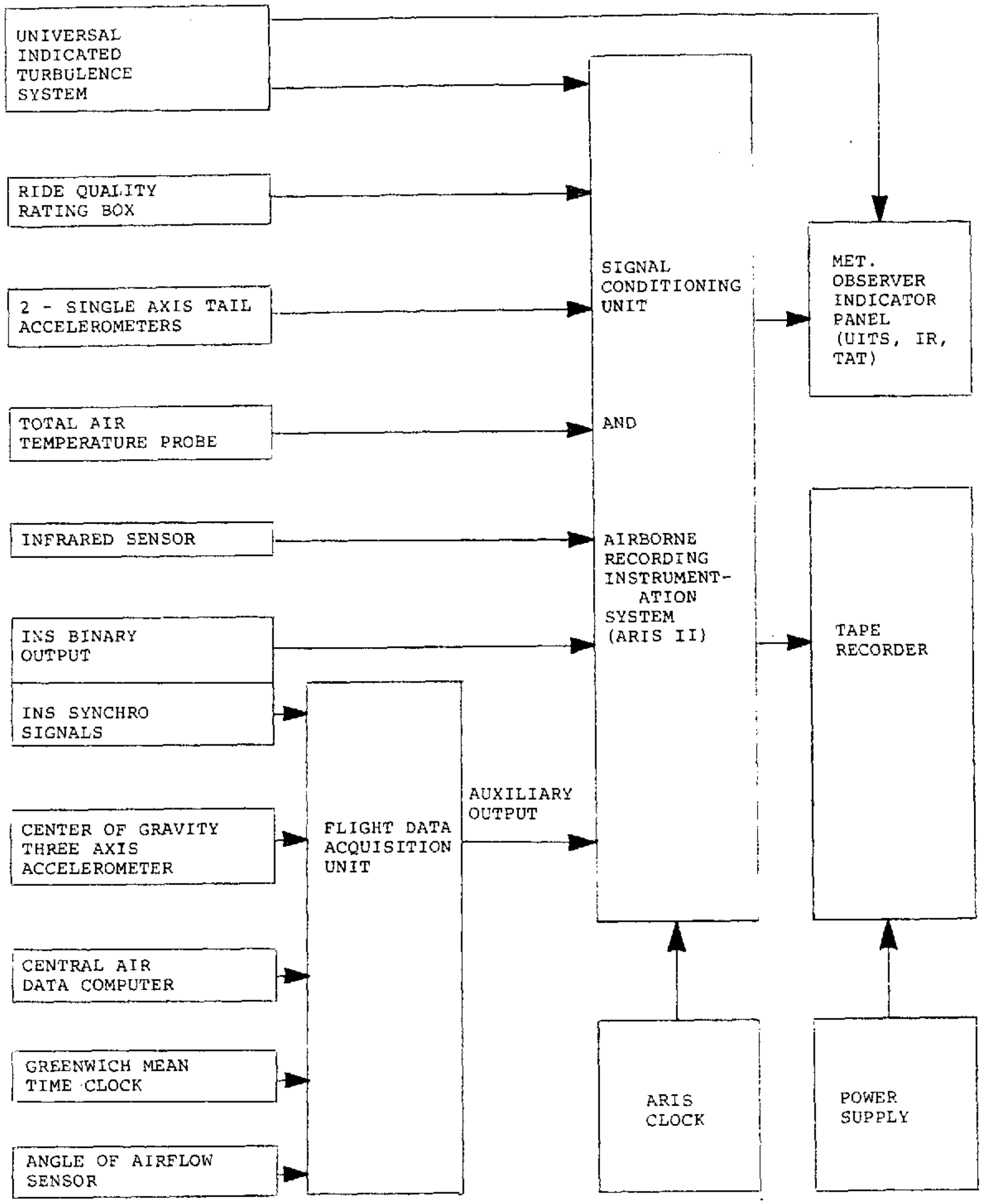

Figure 1. Block Diagram of Inflight Data Collection System for Atmospheric Turbulence Research.

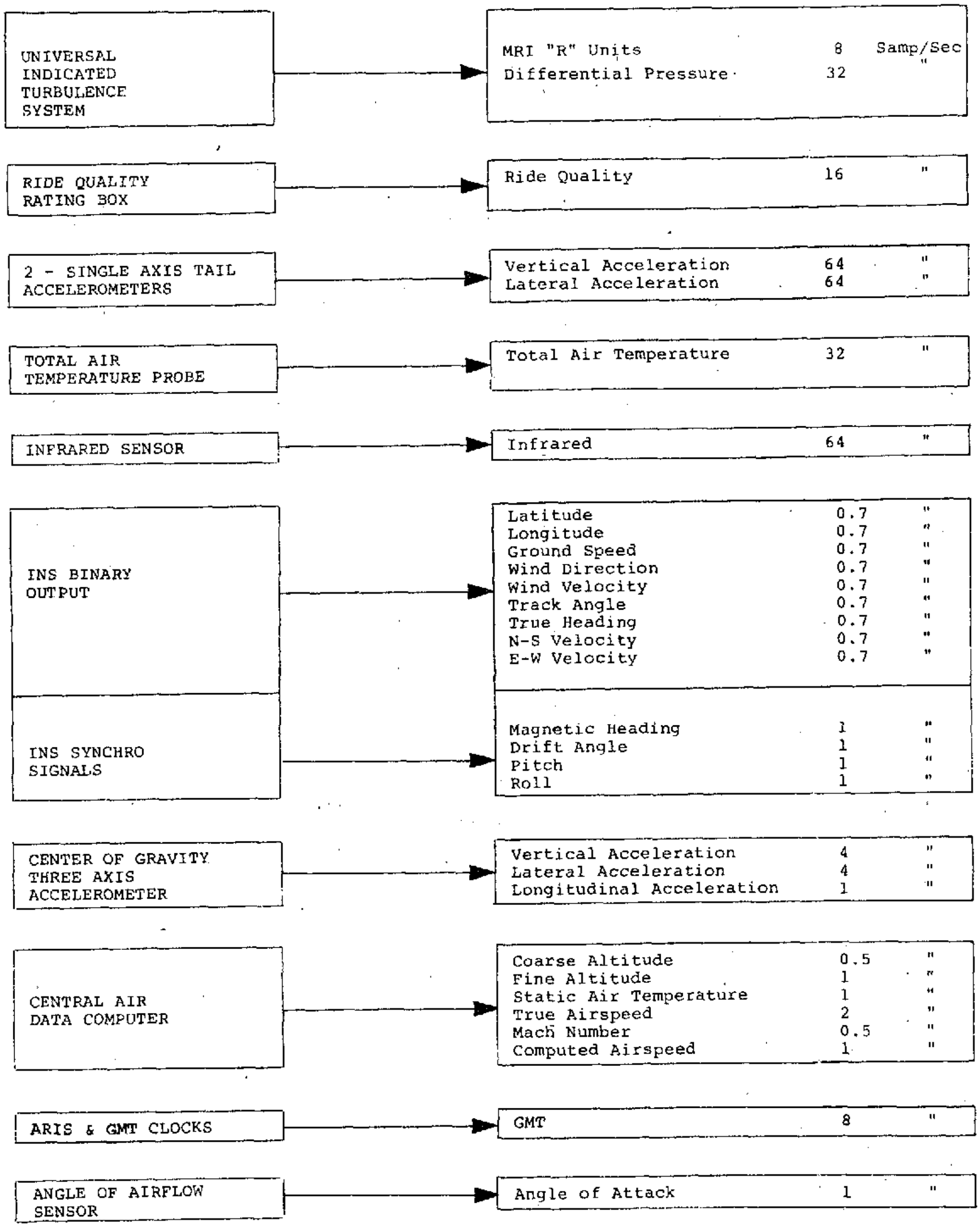

Figure 2. Recorded Parameters and Sampling Rates. The data that were received and recorded from each of the subsystems shown in Figure 1 are shown to the right of that subsystem together with their individual sampling rates.

flights which also eliminated the necessity of changing tape reels more than once per flight.

The Sangamo tape recorder, ride quality rating box, and the two tail-mounted single axis accelerometers utilized a separate 28 volt DC regulated power supply independent of aircraft power. The tape recorder and power supply were installed in mounting racks designed and built by NCAR. The racks were fastened to special base plates that were attached to the floor in the rear left-hand cockpit area. Figure 3 shows the tape recorder and power supply installation in the aircraft cockpit.

Signal Conditioning Unit and Airborne Recording Instrumentation System

All data from the various sensors and systems were merged into a single serial bit stream by the Signal Conditioning Unit and Airborne Recording Instrumentation System (ARIS). This interface between the aircraft sensors and systems and the Sangamo Recorder provided data in a pattern that was decommutable by the NCAR Research Aviation Facility ground station.

The Signal Conditioning Unit was designed and assembled by NCAR solely for this research program. The Airborne Recording Instrumentation System was an NCAR shelf item that had been used on previous research projects and modified for this program, hence the ARIS II designation. As shown in Figure 3, these units were installed above and in the same mounting rack as the tape recorder.

Airborne Recording Instrumentation System Clock

The Airborne Recording Instrumentation System (ARIS II) included an electronic digital clock that generated a Greenwich Mean Time (GMT) signal output. Time signals were transmitted to the special tape recorder which provided the basic parameter for correlating the recorded data from all sensors and systems. The ARIS II clock signal was recorded at a rate of 8 samples per second.

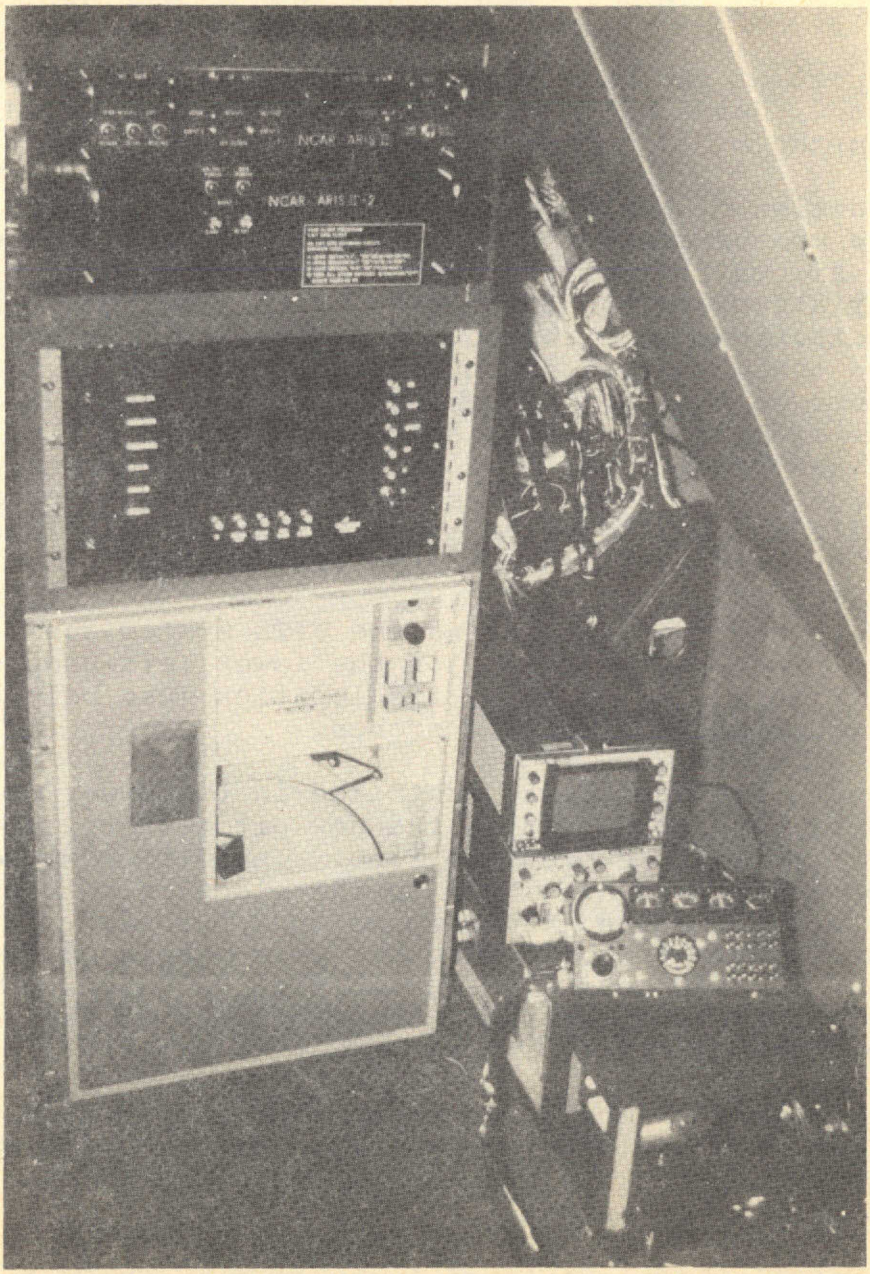

Figure 3. Sangamo Tape Recorder and Power Supply Installed in Mounting Racks Located in Aft Cockpit Area. Also shown are the Signal Conditioning Unit and Airborne Recording Instrumentation System (ARIS II) mounted on top of the tape recorder.

Universal Indicated Turbulence System

In support of the NASA ride quality program, a Meteorology Research, Inc., Universal Indicated Turbulence System (UITS) was installed in the B-747.

The function of the UITS was to provide a meaningful and quantitative measurement of the intensity of turbulence encountered by the aircraft. Inflight measurements were made by sensing pressure variations in a pitot-static system caused by turbulence induced fluctuations in airspeed. A differential pressure transducer sensed these variations and transmitted a DC voltage signal to a miniature computer. The computer processed the differential pressure (pitot minus static) signal to provide a direct current output voltage proportional to the turbulence intensity. These output voltage signals were transmitted to the Sangamo tape recorder and a remote indicator that registered turbulence intensity in "R" units on a zero to ten (10) scale.

For the purpose of evaluating the UITS System, an additional pitot-static probe was installed on the lower left-hand side of the B-747. Figure 4 illustrates its location just below the two existing production pitot-static probes.

A pressure transducer was installed in the lower forward electronics bay and connected to the new pitot-static probe with a 50 centimeter flexible pressure line. The UITS computer was installed on a shock mounted tray in the electronics rack at the rear of the cockpit behind the Sangamo tape recorder. Output voltage signals from the UITS computer were displayed on a remote monitor panel located beside the meteorological observer's seat. Figure 5 shows the location and a close-up view of the indicator on the remote panel.

The UITS was completely independent of any existing aircraft system and operated satisfactorily throughout the data collection program. During the 57 flights, the meteorological observers recorded 361 cases of turbulence.

The subjective evaluation of turbulence by the meteorological observer utilized the commonly accepted terms of: Very Light Chop (VLC), Light Chop (LC), Light Turbulence (LT), Moderate Chop (MC), Moderate Turbulence (MT), and Severe Turbulence (ST). Flight crews also report atmospheric turbulence by using these

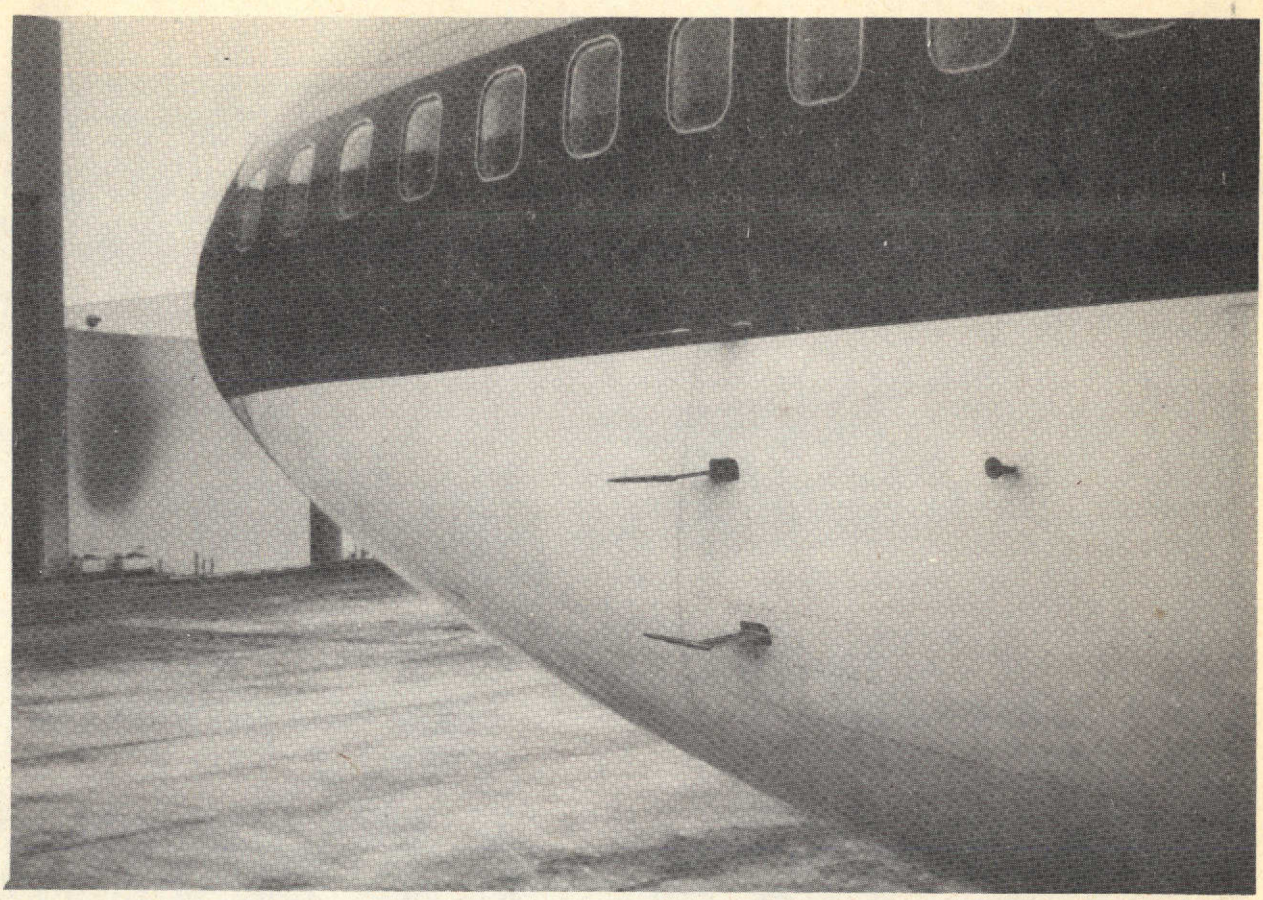

Figure 4. UITS Pitot-Static Probe Located on Left-Hand Side of B-747.

same classifications to subjectively describe the pilot's opinion of the response of the aircraft to the turbulence encounter. In addition, the term "chop" has become universally accepted and is frequently used to specify turbulence of a different character. Chop implies that the turbulence occurs without appreciable changes in altitude and is not the usual updraft/downdraft or rolling motion around one or more of the aircraft axes. Instead, chop is identified as a distinctive, comparatively high frequency, bumpy or jolting motion analogous to driving an automobile over a rough cobblestone road or a fast small boat over rough water. Subjective reports of chop intensity are restricted to very light, light, light to moderate, or moderate categories.

A comparison between the subjective evaluation of the various

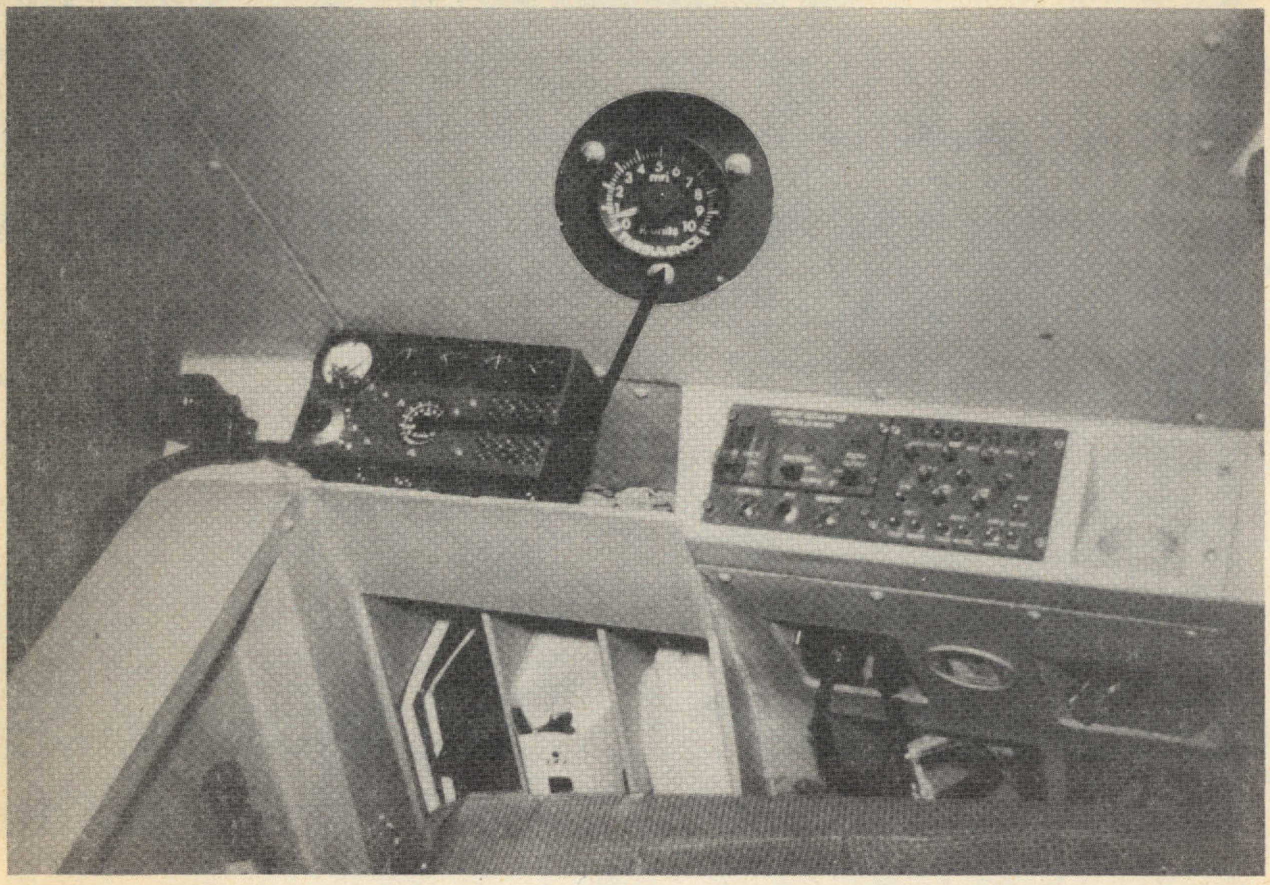

Figure 5. UITS Response Indicator Installed in the Meteorological Observer's Remote Indicator Panel. Insert is an enlarged view of the Indicator.

intensities of turbulence that were experienced on each of the 361 reported encounters and the observed UITS value in "R" units is displayed in Figure 6. The zero to 10 scale of the UITS indicator has been divided into half units to expand the range as an aid in comparing the observer's evaluation with the "R" units. All cases shown in the figure occurred at cruising altitudes.

In Figure 6, it is apparent that the range of UITS "R" units associated with each subjective evaluation of turbulence may seem excessive. However, it should be noted that part of the reason for this disparity is that five observers were involved in making the turbulence evaluations during the data collection program. Of course, it is equally true that each intensity of turbulence occurs within a general range of values regardless if it is reported subjectively or measured with accelerometers and recorded

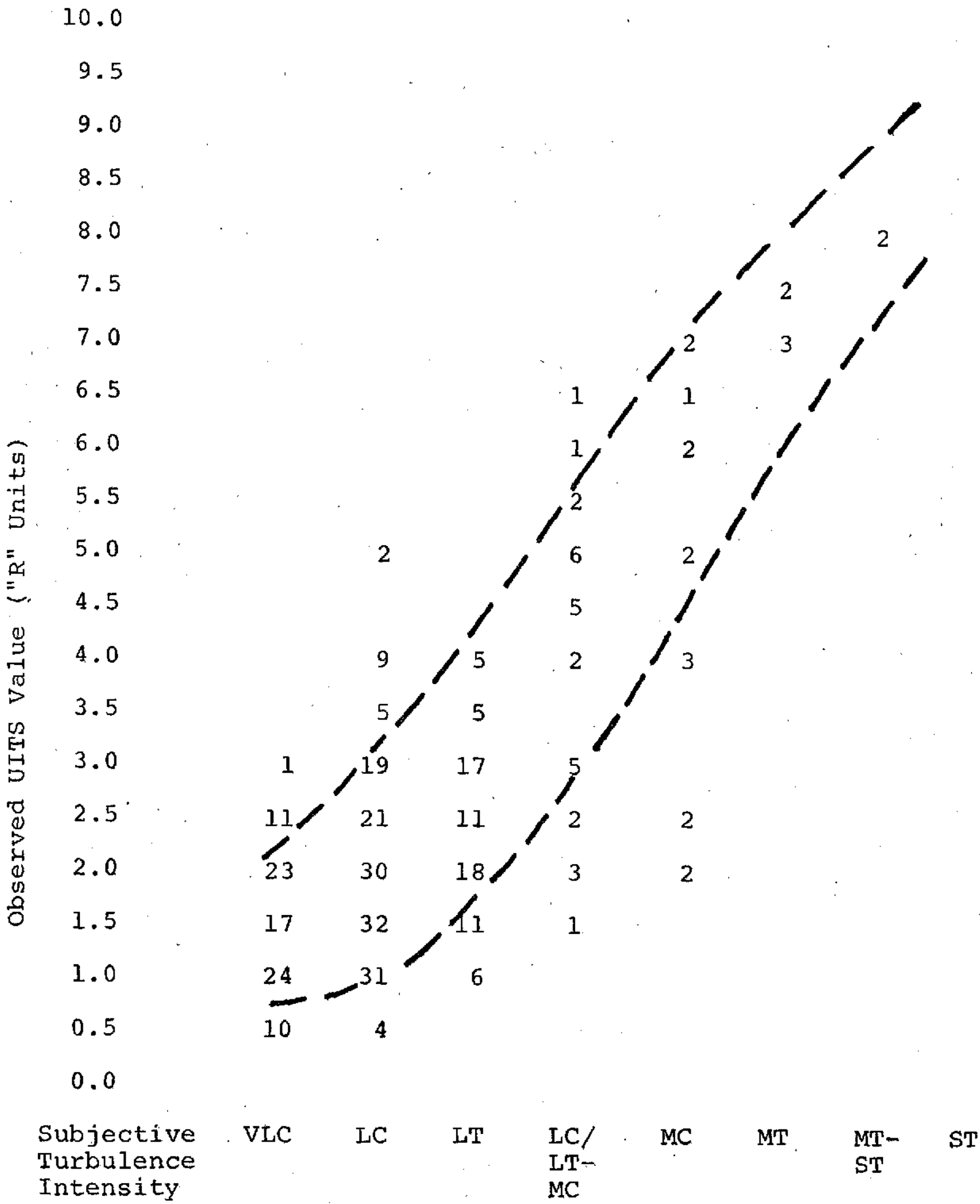

Figure 6. Comparison Between Observed UITS Values and the Subjective Evaluation of Turbulence Intensity for 361 Turbulence Encounters.

for future analysis. Therefore, if the cases within the dashed lines in Figure 6 are considered as representative of the majority, a more realistic evaluation of the correlation between "R" units and turbulence can be made.

The UITS gave the most consistently representative response to turbulence when the aircraft was at cruising altitude. Significantly higher "R" values were observed on the indicator during climb and descent especially below 6 km, even though subjective evaluation of the turbulence intensity was the same.

In addition, it appeared that the response of the UITS was too sensitive over the lower one-fourth of the indicator scale even at cruising altitude. Flight crews that were interviewed on each data flight agreed with this evaluation with reference to the utility of the UITS. Therefore, it is proposed that the scale shown in Figure 7 would be a more meaningful subjective criteria for pilots to use in reporting turbulence intensity. If this or a similar standard scale was established, the current subjective evaluation of turbulence intensity could be eliminated. In order for the Universal Indicated Turbulence System or any other objective measuring device to be effective, the measuring system should be installed on all aircraft in order to standardize pilot reports of atmospheric turbulence.

Ride Quality Rating Box

A portable rating box was supplied by the Flight Research Center for use by their trained observer passengers in conjunction with the ride quality program. The rating box was strapped to the left arm rest of the left outboard seat in the last row of the B-747 passenger cabin. Electrical power to operate the rating box was provided by the cockpit tape recorder 28 volt DC power supply. After each data flight, the rating box was disconnected from the wiring harness and removed from the airplane.

Design of the rating box included five consecutively numbered push buttons that could be depressed by the NASA observer to record his subjective evaluation of passenger comfort in smooth air as well as turbulence. Variable voltage low frequency signals were transmitted to the Sangamo Recorder by depressing one button at a time on the rating box. Thus, the NASA observer's continuous evalation of ride quality was recorded as a discrete signal along with all other data from the aircraft sensors and systems.

0	Smooth
1	Very Light Chop
2, 3	Light Chop/Light Turbulence
4, 5	Light Chop/Light Turbulence - Moderate Chop
6, 7	Moderate Chop/Moderate Turbulence
8	Moderate Turbulence - Severe Turbulence
9	Severe Turbulence
10	Extreme Turbulence

Figure 7. Suggested Turbulence Intensity Scale to Correspond with UITS Indicated "R" Values Based on Subjective Data from the Observation Program.

Figure 8 illustrates the rating box attachment to the arm rest of the passenger seat.

The five (5) buttons of the rating box were basically associated with the following scale for subjectively evaluating ride quality:

1. Very comfortable (as comfortable as possibly can be)
2. Comfortable
3. Neutral (not really comfortable, however, not really uncomfortable)
4. Uncomfortable
5. Very uncomfortable (usually will cause sickness if continued over period of time)

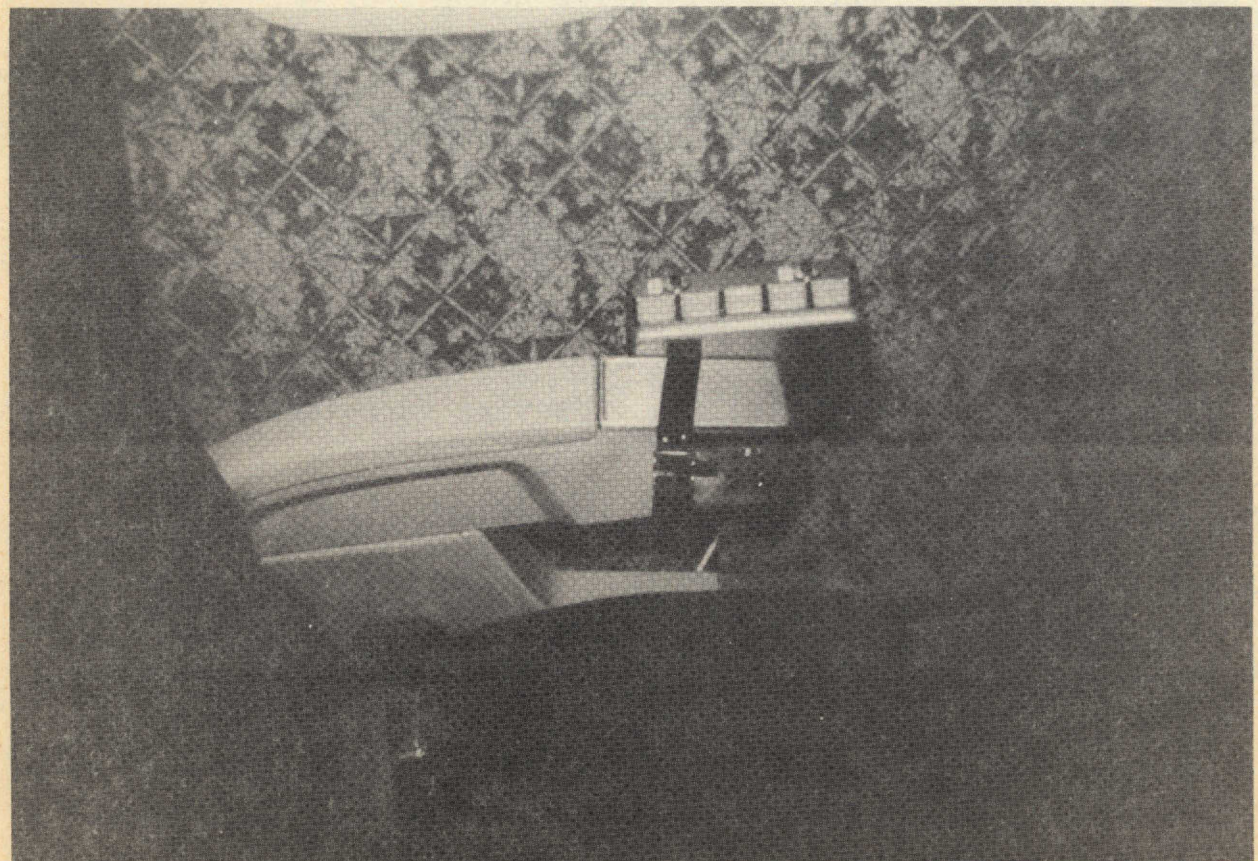

Figure 8. Rating Box Attached to Seat Arm Rest in Rear Passenger Cabin.

The NASA observer's rating could be noted by the meteorological observer monitoring a binary light display on the NCAR Signal Conditioning Unit. This enabled the meteorological observer to compare the subjective analysis of ride quality from both the rear passenger cabin and cockpit of the aircraft.

As expected, the NASA observer was usually more critical of aircraft response to a turbulence encounter than the meteorological observer. It was also noted that when turbulence increased in intensity, the NASA observer generally responded to this condition with quick changes in the rating box scale to reflect the decrease in ride comfort. In contrast, the observer's reaction toward the improvement in ride quality was usually much slower when turbulence decreased in intensity. Furthermore, it was noticed that if the same degree of turbulence was encountered for a long period of time, the observer would increase his discomfort rating. This indicates that the duration of turbulence is also a factor in assessing passenger comfort. Of course, it is also a generally accepted fact that passengers respond more critically to turbulence in the tail section of a long swept wing airplane than passengers in front or the crew in the cockpit.

During the data collection program, rating box data were lost on three (3) flights and recorded intermittently on two (2) others. This was due to a faulty wire connection in the rating box and broken wires in the power supply connector. The observers on these flights took extensive notes to cover the loss in recorded rating box data.

Tail Section Accelerometers

NASA provided two Donner, Model 4310, single axis accelerometers that were installed in the overhead center ceiling area above the rear lavatories in the tail of the B-747. The accelerometers measured vertical and lateral motions of the tail section of the airplane.

The Donner linear accelerometer functions as a miniature servo system measuring input accelerations along its sensitive axis to an accuracy of 0.1%. The accelerometers operated on 28 volt DC power with the following range scales.

Vertical . . . $\pm$ 2.0 g full scale; calibrated $\pm$ 1.0 g
Lateral . . . $\pm$ 0.5 g full scale; calibrated $\pm$ 0.5 g

Output signals from the two accelerometers were transmitted to the Sangamo recorder to provide an objective recording of aircraft response to atmospheric motions. These data were then compared with the subjective analysis supplied by the NASA observer to provide a more complete description of aircraft response and ride quality.

Operational tests during the first three data collection flights indicated the vertical accelerometer was transmitting intermittent output signals to the recorder. With the replacement of the faulty unit after the fourth data flight, the tail accelerometers functioned normally on all subsequent flights.

Total Temperature Sensor

Results from earlier clear air turbulence research programs have substantiated the theory that a general correlation exists between the rate and magnitude of atmospheric temperature changes and the occurrence of significant CAT (ref 1,2). Flight data collected on these research programs included temperature information from the relatively slow response aircraft temperature sensors on commercial and military jet aircraft. However, it is also believed that possible large and very rapid fluctuations of temperature are caused by the more significant intensities of turbulence. Fortunately, with the recent development of very fast response temperature sensing systems, evaluation of this important additional factor in the temperature-turbulence relationship is now possible.

To provide the required microscale temperature information, a Rosemount Total Temperature Sensor, Model 102CV2DF, was installed on the B-747 aircraft. It was located on the aircraft's nose just ahead of the windshield (as shown in Figure 9) in the same area as the existing standard Total Air Temperature (TAT) probes. This special sensor contained a replaceable 50 ohm open-wire platinum sensing element and a 115 VAC deicing heater. Wind tunnel tests conducted by the manufacturer determined the time response of the sensor to be 12 milliseconds.

During a data flight in December, the resistance element of the sensor failed. Because considerable time was needed to replace the broken element, a spare TAT sensor with the same time response was loaned to Continental by NCAR to complete the research program. A total of four (4) data collection flights (No. 26-29) were flown with the broken sensor element. On all other research flights, the Total Temperature Sensor functioned properly and transmitted continuous data to the Sangamo recorder.

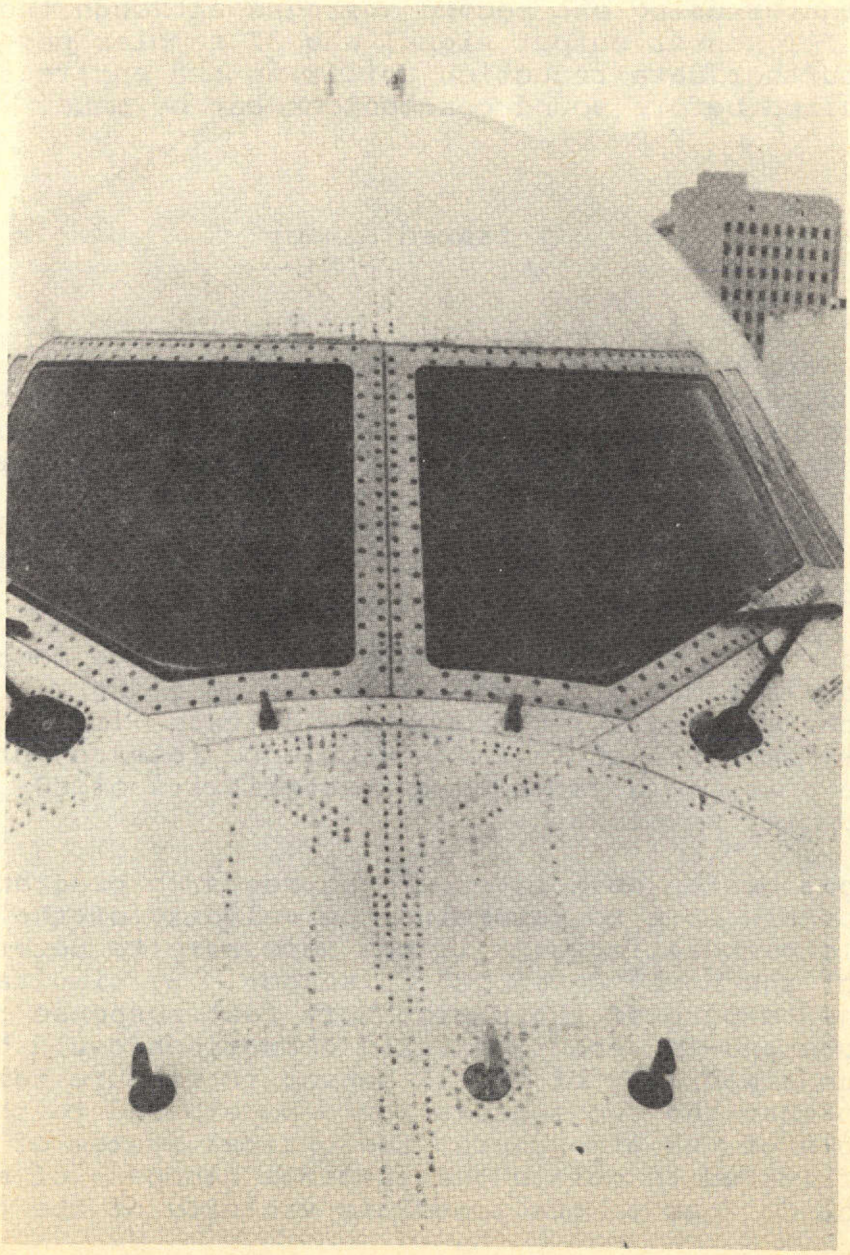

Figure 9. Location of Fast Response TAT Probe. The Rosemount Total Temperature Sensor was located on the nose of the aircraft about halfway between the two existing slower response Total Air Temperature Probes.

A preliminary analysis of TAT data has shown that very fast response temperature changes were recorded during the occurrence of significant turbulence. However, these data were reduced by the NCAR computer using one second averages although the sampling rate of the TAT sensor output signal was 32 samples per second. Therefore, further data reduction utilizing the entire sampling rate is required before sound conclusions can be made.

Infrared Sensor

The temperature/turbulence relationship was first proposed well over a decade ago. Operational experience during the ensuing years has continued to emphasize the necessity of providing the flight crew with adequate warning time to minimize the effects of rough air penetration or, if possible, avoid it completely. Therefore, it is evident that temperature gradients must be measured well ahead of the aircraft if they are to be useful in detecting turbulence.

Rapid advancements in infrared technology have demonstrated that atmospheric temperature anomalies can be measured remotely due to the thermal radiation properties of gases (ref. 3). The infrared (IR) sensor used in this turbulence research program measured the emission/absorption characteristics of CO_2 gas near the 15 micrometer wavelength.

Since one of the objectives of the research program was to record microscale data to determine the validity of the temperature/turbulence relationship, it was necessary to determine the efficiency of the newly developed IR sensor. By simultaneously recording the outputs of the proven very fast response total temperature probe and IR sensor, a valid comparison could be made to determine the capability of the IR sensor to measure temperature changes. So that the two sensors would be exposed to the same general sample of the atmosphere, the optical system of the IR sensor was filtered to obtain the spectral bandpass of maximum absorption of CO_2 gas in the immediate vicinity of the aircraft.

The IR sensor was installed in a special pylon assembly built by NCAR. The pylon, which conformed to an NACA 0030 airfoil, was mounted on top of the aircraft aft of the cockpit smoke evacuation hole. Figure 10 shows the pylon and IR sensor installation. The pylon was 20 cm high to eliminate the possibility of turbulent boundary layer air affecting the sensor.

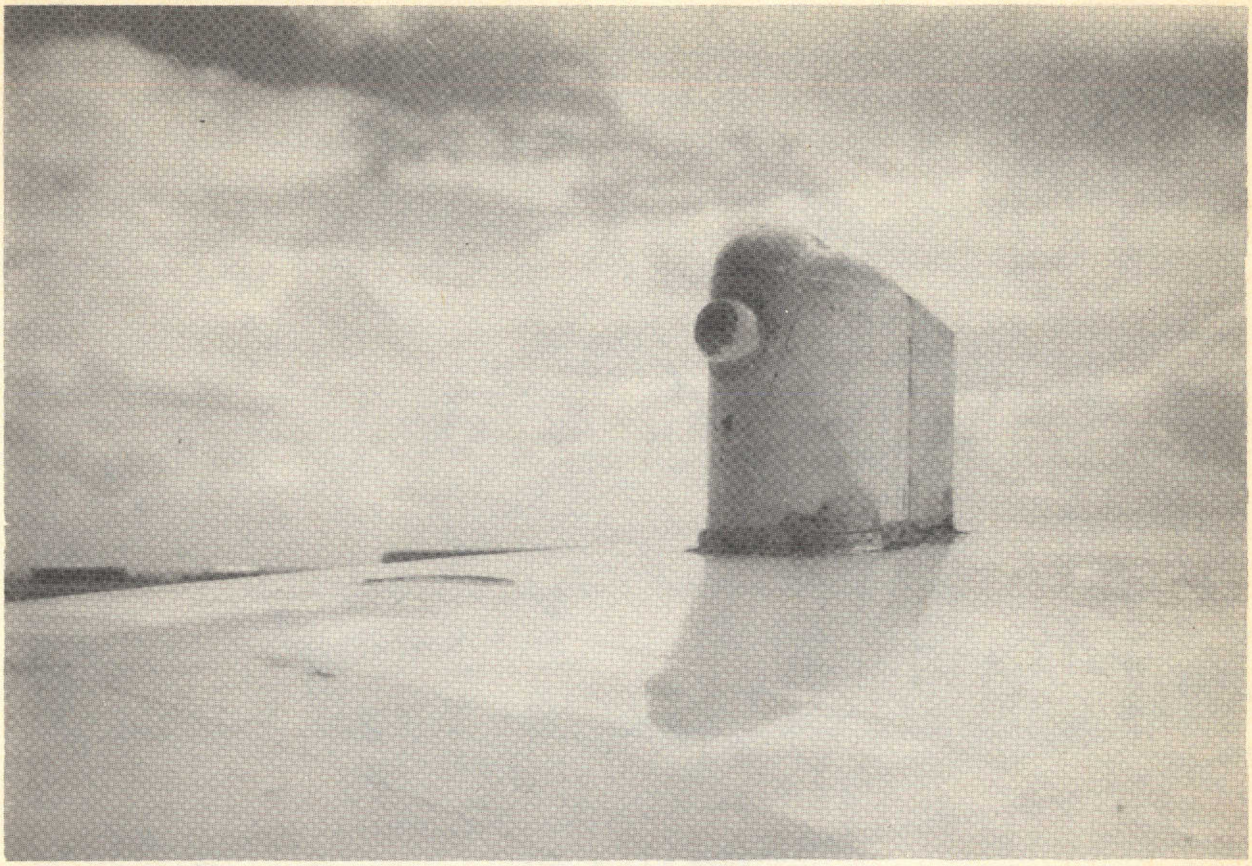

Figure 10. Infrared Sensor Within the Airfoil Shaped Pylon Mounted on Top of the Aircraft.

Thermal anti-icing was provided to prevent ice accretion. Figure 11 illustrates the internal mounting of the entire sensor to the top plate of the pylon. For the purpose of the photograph, the sensor and top plate are in the inverted position.

After the pylon was mounted on top of the aircraft, considerable wind noise was generated at cruising air speeds. In an effort to eliminate the noise problem, NCAR modified the pylon by adding a thin vertical fin approximately 20 cm high by 11 cm long to the tail of the pylon. Several layers of fiberglass were also attached to the outside skin around the base of the pylon to minimize vibration. These modifications, combined with the installation of soundproofing foam inside the airplane directly under and aft of the pylon installation, eliminated pylon generated wind noise in the first class upper lounge.

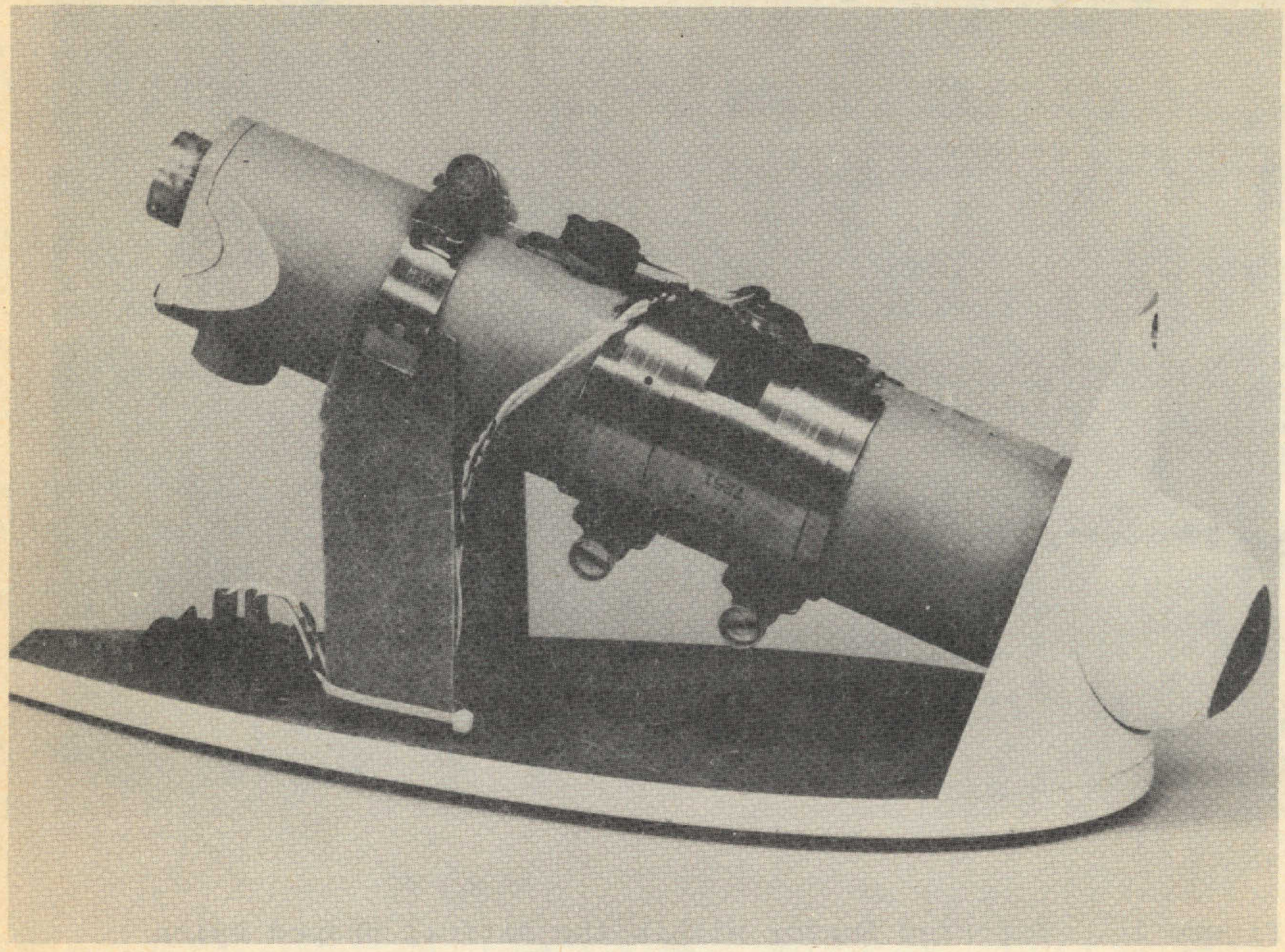

Figure 11. IDIS - 5X1A Mounted to Top Plate of the Pylon. (Sensor and top plate are inverted in the figure compared to their normal position).

Rockwell International Autonetics Division manufactured the Model IDIS-5X1A infrared sensor and consigned it to Continental Airlines for this program. The passive detector was designed to detect atmospheric thermal microstructure less than 300 meters in wavelength at an aircraft speed of 250 meters/second (Mach .84) (ref.4). The optical system was filtered in the spectral bandpass of 14.1 to 15.1 micrometers to include the maximum absorption frequency of CO_2 gas. The optical beam length was relatively short, with 70 percent of the emission within 1700 meters at an altitude of 10,700 meters. Since the field of view was 34° X 34° or .35 steradians solid angle, the sensor was tilted upward 20° from the aircraft longitudinal axis to avoid field of view contact with the aircraft roof.

The sensor was designed to indicate small thermal changes within a range of approximately 90 meters. Details of the sensor were as follows:

1. Size, 5 cm diameter cylinder, 27 cm long.
2. Weight, 725 gms.
3. Power input, 28 volt DC x 10 MA = 0.28 watts.
4. Output, 1 volt per degree Celsius change.
5. Range, 90 meters.
6. Response, 6 milliseconds.
7. Resolution, $\pm$ 0.010°C at 5 HZ and 1 HZ bandwidth.

The source of power for the infrared sensor was a Lambda regulated power supply. It was installed in the same mounting rack as the tape recorder power supply.

During the preliminary reduction of the flight data, NCAR computed one second averages of the various sampling rates of all sensors. Of course, this smoothing technique precluded the opportunity of seeing rapid and minute fluctuations of the infrared signal and consequently, microscale temperature fluctuations. Since the sampling rate of the infrared signal was 64 samples per second, it is evident that the capability of the IR sensor to detect rapid temperature fluctuations cannot be evaluated completely until all the data are reduced without the application of the averaging technique.

Flight Data Acquisition Unit

In order to record all data in a serial digital format, an interface was needed to convert the analog signals of some aircraft parameters to a digital form. This was accomplished with the installation of a Teledyne Expandable Flight Data Acquisition and Recording System (EFDARS) Model No. 70-200.

The Expandable Flight Data Acquisition and Recording System is an airborne data system designed to continuously sample and record analog and digital aircraft parameters and store this information in a crash-protected recorder. The basic system includes a Flight Data Acquisition Unit (FDAU) for signal conversion, a Digital Flight Data Recorder (DFDR) for continuous recording of aircraft data from all monitored systems, a Three Axis Accelerometer for measuring aircraft vertical, lateral, and longitudinal accelerations and a Flight Data Entry Panel (FDEP) for manual insertion of flight number and date by a crew member.

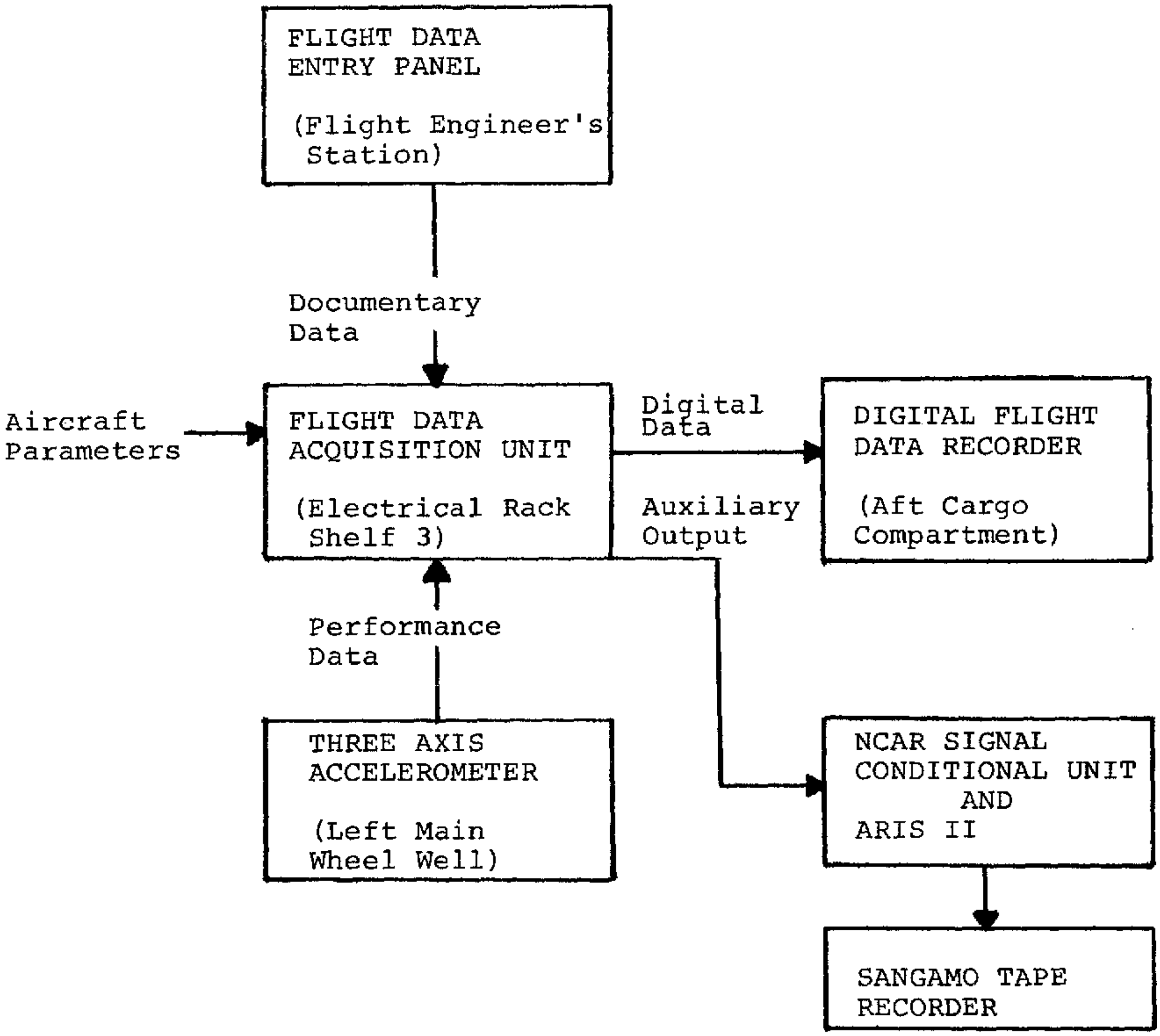

Figure 12. Block Diagram of the Expandable Flight Data Acquisition and Recording System. Also shown is the location on the aircraft of the units comprising the EFDARS plus the NCAR tape recorder and interface.

A block diagram of the EFDARS and the assigned location of each of the units that comprise the system is provided in Figure 12. As shown in the diagram, the interface between the EFDARS and the Sangamo Tape Recorder was made through the use of an FDAU auxiliary output. The FDAU auxiliary output provided an input to the NCAR Signal Conditioning Unit that was identical to the signal being recorded on the DFDR. Therefore, monitoring the DFDR during the research program was not necessary.

Aircraft signals selected for sampling were routed directly to the Flight Data Acquisition Unit for processing. The FDAU provided the necessary electronics to isolate, precondition, multiplex and convert analog signals into a standard digital format. Multiplexing provided a means of selecting one parameter at a time for signal processing. Preconditioning was used to scale the various signal amplitudes to the same level to retain the resolution of the low level signals. A central converter was used to digitize all types of analog input signals. These FDAU processed signals were then transmitted in serial digital form to the tape recorder.

Center of Gravity Three Axis Accelerometer

The Three Axis Accelerometer was used to measure vertical, lateral, and longitudinal acceleration at the aircraft's center of gravity. As mentioned above, the Three Axis Accelerometer was part of the Expandable Flight Data Acquisition and Recording System and was located in the left main wheel well (see Figure 12). It was a sealed unit with no external adjustments and operated on a 28 volt DC power input. The range of the Three Axis Accelerometer was as follows:

Vertical ...... - 3 g to + 6 g full scale
Lateral ...... ± 1 g full scale
Longitudinal .. ± 1 g full scale

These measurements were recorded simultaneously along with data from the tail accelerometers for the purpose of comparing aircraft response during turbulence.

Inertial Navigation System

The Inertial Navigation System (INS) automatically computed navigation and attitude data to calculate the aircraft's relationship to a desired great circle course. This was accomplished through the use of inertial components (gyros and accelerometers) and a computer that continuously determined the position of the aircraft over the earth's surface projected forward from a predetermined initial position known at the time of takeoff. No external navigation aids except true airspeed inputs from the Central Air Data Computer (CADC) were required by the INS.

The Continental Boeing 747 utilized three (3) separate Litton LTN-51 Inertial Navigation Systems. Synchro and binary signals selected for recording were provided by the No. 3 INS. Figure 2 illustrates the parameters that were received from these outputs. The No. 3 INS Control Display Unit (CDU) was located on the aft central pedestal. From the jump seat, the meteorological observer could operate the data selector switch and manually record the various INS parameters that were provided continuously in a numerical display. This enabled the observer to note real time data associated with a turbulence event.

Central Air Data Computer

The Central Air Data Computer (CADC) supplied computed air data from information received from dynamic (pitot) pressure, ambient (static) pressure, and total air temperature which were sensed external to the aircraft. With the availability of dual systems on the B-747, selected outputs from the No. 2 Bendix CADC were connected to the FDAU for signal conditioning prior to recording. The same data were transmitted to the aircraft's flight control, inertial navigation, and air data instrumentation systems. The computed air data functions that were recorded included altitude (coarse and fine), true airspeed (TAS), computed airspeed (CAS), Mach number, and static air temperature (SAT).

Greenwich Mean Time Clock

A Hayden Greenwich Mean Time (GMT) clock with an output for recording time was installed in the captain's panel in place of the original Boeing 747 clock. The primary purpose of the clock was to provide a GMT digital readout for the meteorological observer. In addition, the GMT clock output signal was transmitted to the FDAU and ARIS II for conditioning and subsequent recording as a backup for the ARIS II clock. Before each flight, the GMT clock was set with the correct time obtained by radio from the National Bureau of Standards, Station WWV. The ARIS II electronic clock was then started and set with the identical time.

Angle of Airflow Sensor

Angle of attack was an additional data source that was recorded after the start of the program at the request of NCAR. This parameter was obtained from the angle of airflow sensor which is part of the aircraft stall warning system. The sensor is located on the outside of the fuselage below the captain's side window. It consists of an aerodynamic vane which positions the rotor of a synchro. The counter-balanced vane is free to rotate through 360 degrees and is operative through 120 degrees. Inflight, the vane assumes a position parallel to the airflow passing over it. The sensor generates a synchro signal that is converted to a digital format by the FDAU and processed by the signal conditioning unit and ARIS II for recording.

Since angle of attack was an add-on parameter, the first seven (7) data collection flights do not contain these data. However, on all subsequent flights angle of attack was recorded.

Meteorological Observer's Indicator Panel

A meteorological observer's panel was designed and built by NCAR to house the UITS response indicator and several ammeters (see Figure 5). Inputs to this panel were from the ARIS II System and the UITS computer via a three (3) meter long flexible wiring harness. Thus, the meteorological observer could move the indicator panel to a convenient position near the jump seat for inflight observation and also stow it behind the tape recorder power supply at the end of each trip.

The ammeters were provided to display visual indications to the observer that the fast response Total Temperature Sensor, Infrared Sensor, and UITS pressure transducer were functioning properly. The "R" units from the UITS response indicator were the only values that could be read directly since conversion scales to engineering units were not available on the other indicators.

INSTALLATION AND FLIGHT TEST

Installation of the special equipment, instruments, and sensors required for the data collection program was accomplished on a piecemeal basis that was dependent on the availability of the aircraft for maintenance. Initial installation of wiring bundles began in early January 1973. On June 11, 1973, installation of the final components of the entire system was completed. Due to modifications in aircraft structure and avionics systems, the Federal Aviation Administration (FAA) required that Continental Airlines obtain a Supplemental Type Certificate (STC) to insure that performance in flight of any system, component or structure was not compromised. Upon completion of the installation, a conformity inspection was accomplished by the FAA to determine that all specified work was done as directed. The FAA also conducted an electrical and electronics interference ground check. A test flight to carry out additional inflight checks of all applicable aircraft systems was performed to complete the requirements for the STC. On June 12, 1973, Continental Airlines was awarded an STC for B-747 aircraft N-26864.

Preliminary flights during the summer months were conducted primarily to check out the equipment. Since most clear air turbulence occurs normally from October through March, data collection flights were begun the last week of September, 1973. Fifty-seven flights were completed by January 10, 1974, at which time Continental Airlines removed all B-747 aircraft from service, as a result of the international fuel crisis.

FLIGHT DATA

During the initial period of data collection flights, all CAL B-747 aircraft were assigned exclusively to the Los Angeles-Honolulu route. However, during the month of October, an equipment substitution was made on one daily round trip between Los Angeles and Chicago. As a result, fourteen data flights were made over the plains and mountains of the western half of the United States. With the exception of one additional round trip on the Los Angeles-Chicago route in December, the remaining data flights were conducted over the Eastern Pacific Ocean on the Los Angeles-Honolulu route. A round trip between Los Angeles and Chicago or between Los Angeles and Honolulu was counted as two (2) flights when data were gathered. Appendix A summarizes the dates and times of the data collection flights.

Meteorological conditions that were observed during the progress of each flight were recorded manually by the meteorological observer. Atmospheric phenomena such as cloud type, amount, density and thickness were recorded in detail on horizontal and vertical cross sections. These cross sections also included intensity, types, and duration of turbulence events, real time wind flow data from the INS, and pilot reports from other aircraft. Special emphasis was placed on recording turbulence encounters with regard to their occurrence in clear air, cirrus, or in an area of convective storms. Orographic influences that produced mountain wave activity were noted on the cross sections. When the flight was on instruments, airborne weather radar was also used extensively to determine if convective activity or jet stream cirrus was the primary cause of turbulence. Visual observations of UITS values and ride quality ratings during turbulence events were also recorded as well as conventional aircraft performance data displayed in the cockpit.

In addition to the horizontal and vertical cross sections and other special meteorological observer forms, copies of all pertinent surface, radar, and upper air weather charts were obtained for future reference and study. If a particular research flight encountered significant turbulence, radiosonde data were plotted for those stations near the flight route to determine the vertical temperature and wind profile in the turbulent area. A complete file containing all these data was compiled for each flight in preparation for analysis.

A time hack was made before the departure of each research flight to synchronize the data recorded by the meteorological observer and the NASA observer. The GMT clock was used as the source of this information to correlate human observations with all aircraft sensor and system inputs to the special flight recorder.

Recorded data from each research flight were sent to NCAR and reformatted into computer compatible tapes. After further processing, new tapes were made that provided digital and analog printouts expressed in engineering units. These data were then transferred to 35mm microfilm in preparation for analysis. An example of the digital data provided by the NCAR CDC 6600/7600 computer system is shown in Figure 13. A short period of 60 seconds is presented to illustrate the type of data that were re corded during the flight program. Time in hours, minutes, and seconds in the first column on the left side of each of the thre portions of the figure is the only parameter that is common to each page of data. Although the sampling rates varied from .5 to 64 per second, this printout contains only one second average of the sampling rates of each of the 34 listed data sources. Figure 14 identifies these parameters as well as the units in which they are expressed.

HR	MI	SEC	PA MBAR	IR	TAT DEG C	LAC G	VAC G	MRI	ILAT DEG	ILON DEG	GSI KNTS	TRACK DEG	THI DEG	WSI KNTS
00	17	1.8	113.53	2.3	-22.9	.01	.96	.8	35.79	-114.41	497.0	255.0	240.1	44.0
00	17	2.8	114.05	2.2	-22.2	.01	.99	1.2	35.79	-114.41	497.0	255.0	240.0	42.6
00	17	3.8	113.44	2.4	-22.6	-.01	1.02	2.0	35.79	-114.41	497.0	255.1	259.9	41.5
00	17	4.8	115.42	2.6	-22.2	-.02	1.05	2.6	35.79	-114.41	497.0	255.0	240.0	43.1
00	17	5.8	116.63	2.6	-21.6	-.02	1.02	3.3	35.79	-114.42	497.0	255.0	240.2	43.6
00	17	6.8	114.79	2.4	-22.2	-.01	1.00	4.0	35.78	-114.42	497.0	255.0	240.3	45.4
00	17	7.8	114.08	2.2	-22.4	.02	.99	3.9	35.78	-114.42	497.0	255.0	240.4	47.0
00	17	8.8	113.76	2.4	-22.4	.01	.99	3.7	35.78	-114.42	497.0	255.0	240.3	46.1
00	17	9.8	114.13	2.6	-22.4	-.01	1.01	3.5	35.78	-114.42	497.0	255.0	240.3	46.7
00	17	10.7	114.90	2.4	-22.2	.00	.99	3.5	35.78	-114.43	496.8	234.9	240.2	46.6
00	17	11.7	115.66	2.2	-22.2	-.00	.96	3.4	35.77	-114.43	496.1	234.9	240.0	44.2
00	17	12.7	114.83	2.5	-22.4	.00	.96	3.5	35.77	-114.44	495.9	234.9	239.9	43.6
00	17	13.8	114.44	2.5	-22.6	-.02	.94	3.8	35.77	-114.44	496.0	234.9	240.1	44.9
00	17	14.7	115.20	2.3	-22.3	-.02	.94	3.8	35.77	-114.44	496.0	234.9	240.5	47.9
00	17	15.7	114.71	2.3	-21.8	.04	.93	3.9	35.77	-114.44	496.7	234.9	240.3	48.5
00	17	16.7	114.34	2.3	-21.9	.02	.95	3.8	35.77	-114.44	497.1	234.9	240.0	46.4
00	17	17.7	114.67	2.3	-22.3	-.03	1.06	3.6	35.77	-114.45	497.0	234.9	240.0	43.0
00	17	18.7	114.56	2.2	-22.3	-.01	1.02	3.6	35.77	-114.45	497.0	234.3	240.3	44.4
00	17	19.7	114.21	2.2	-22.2	.02	.98	3.8	35.77	-114.45	497.0	234.9	240.3	45.1
00	17	20.7	115.50	2.3	-21.8	.00	.94	4.1	35.76	-114.45	497.0	234.9	240.1	45.0
00	17	21.7	116.14	2.3	-21.6	.00	.95	4.3	35.76	-114.45	497.0	234.9	240.0	45.1
00	17	22.7	115.80	2.1	-21.8	-.01	.97	4.2	35.76	-114.46	497.0	234.9	240.0	44.5
00	17	23.8	115.78	2.2	-22.1	-.02	.97	3.9	35.76	-114.46	497.0	234.9	240.0	44.0
00	17	24.7	117.43	2.2	-21.4	.02	.99	3.9	35.76	-114.46	497.0	234.9	240.0	44.1
00	17	25.7	118.33	2.1	-20.9	.02	.95	4.2	35.76	-114.46	497.1	234.9	239.8	42.5
00	17	26.7	120.47	2.1	-20.6	-.04	1.06	5.0	35.76	-114.46	496.8	234.9	239.8	42.9
00	17	27.7	120.66	2.1	-20.3	-.03	1.03	5.4	35.76	-114.47	496.0	234.9	240.3	46.8
00	17	28.8	117.57	2.2	-20.5	.05	.93	5.5	35.75	-114.47	495.9	234.9	240.4	47.5
00	17	29.7	118.87	2.2	-19.8	.08	.94	5.9	35.75	-114.47	496.0	234.9	239.8	42.3
00	17	30.7	119.78	2.1	-20.0	-.03	1.05	6.2	35.75	-114.48	496.0	234.9	238.8	33.0
00	17	31.7	117.36	2.1	-21.1	-.07	1.06	6.9	35.75	-114.48	496.1	234.9	239.1	35.7
00	17	32.7	117.75	2.2	-21.1	-.02	1.05	7.6	35.75	-114.48	495.6	234.9	239.7	40.9
00	17	33.8	117.54	2.2	-21.1	.03	1.03	7.8	35.75	-114.48	495.0	234.8	240.2	45.1
00	17	34.7	115.92	2.0	-21.6	.02	1.00	7.5	35.75	-114.48	495.0	234.8	239.8	43.4
00	17	35.7	115.88	2.0	-22.1	-.02	1.03	7.6	35.74	-114.49	494.6	234.8	239.9	43.8
00	17	36.7	115.02	2.2	-22.3	.03	.95	7.5	35.74	-114.49	493.8	234.8	240.1	44.9
00	17	37.7	114.31	2.2	-22.7	.02	1.00	6.6	35.74	-114.49	493.1	234.8	239.5	43.2
00	17	38.8	114.93	2.0	-23.5	-.07	.98	5.7	35.74	-114.49	493.0	234.9	240.2	42.7
00	17	39.7	114.53	2.1	-23.9	-.05	.97	5.0	35.74	-114.50	492.8	235.0	241.2	45.8
00	17	40.7	112.52	2.3	-24.3	.03	.97	4.4	35.74	-114.50	492.1	235.1	241.6	54.3
00	17	41.7	111.25	2.2	-24.7	.01	.95	3.7	35.74	-114.50	491.7	235.3	241.7	54.9
00	17	42.7	111.26	2.2	-25.0	-.01	1.02	3.1	35.73	-114.50	490.7	235.5	241.8	54.3
00	17	43.8	110.84	2.2	-25.1	.01	.95	2.8	35.73	-114.50	490.0	235.7	242.1	55.1
00	17	44.7	110.29	2.2	-25.4	.01	1.01	2.5	35.73	-114.51	489.3	235.9	241.7	50.5
00	17	45.7	112.57	2.1	-25.7	-.04	1.00	2.0	35.73	-114.51	489.0	236.1	241.9	50.8
00	17	46.7	113.03	1.9	-24.4	.01	.90	2.4	35.73	-114.51	489.0	236.3	242.6	54.9
00	17	47.7	111.31	2.3	-23.7	.04	.94	3.7	35.73	-114.51	488.3	236.5	242.0	48.2
00	17	48.8	111.62	2.4	-24.4	-.07	.98	4.4	35.73	-114.52	487.6	236.7	241.9	45.4
00	17	49.7	112.79	2.2	-24.5	-.06	.98	4.5	35.73	-114.52	486.9	236.7	242.5	47.6
00	17	50.7	111.96	2.4	-24.2	.04	.94	4.7	35.73	-114.52	486.1	236.9	243.4	54.1
00	17	51.7	110.30	2.5	-25.0	.04	1.04	4.4	35.72	-114.52	486.0	237.0	243.3	52.5
00	17	52.7	111.89	2.5	-26.0	-.03	1.04	3.5	35.72	-114.53	485.9	237.1	243.0	48.9
00	17	53.8	111.73	2.2	-25.9	-.02	.98	2.7	35.72	-114.53	485.1	237.2	243.2	50.7
00	17	54.7	111.68	2.3	-25.8	.01	1.01	2.0	35.72	-114.53	484.9	237.3	243.4	51.7
00	17	55.7	112.39	2.5	-26.2	.01	.97	1.6	35.72	-114.53	485.0	237.3	243.5	52.1
00	17	56.7	112.74	2.4	-26.1	-.00	.93	1.2	35.72	-114.54	485.0	237.4	243.5	52.0
00	17	57.7	110.73	2.2	-25.8	.00	.88	.9	35.72	-114.54	484.3	237.4	243.5	51.3
00	17	58.8	109.44	2.4	-25.6	-.01	.93	1.5	35.72	-114.54	483.9	237.4	243.6	51.1
00	17	59.7	110.52	2.6	-24.6	.02	1.00	2.8	35.72	-114.54	484.0	237.4	243.7	51.0
00	17	60.7	111.01	2.6	-24.0	.02	.99	4.2	35.71	-114.54	483.3	237.5	243.3	48.2

Figure 13. Digital Printout of 60 Seconds of Recorded Data. A one second average of the individual sampling rates was computed for each of the thirty-four recorded parameters.

HR	MI	SEC	WDI DEG	MHF DEG	FVAC G	FLAC G	PITCH DEG	MACH	TAS KNTS	CAS KNTS	ALT CRS FT	DA DEG	LON ACC G	ALT FT
00	17	1.8	337.0	225.8	.956	.015	1.2	.605	485.9	260.2	38974	-5.6	.057	39457
00	17	2.8	337.2	225.5	1.010	-.011	1.1	.605	485.8	261.6	38974	-5.4	.059	39455
00	17	3.8	339.0	225.3	1.013	-.024	1.1	.603	485.7	260.5	38974	-5.1	.040	39454
00	17	4.8	341.6	225.2	.992	-.002	1.2	.601	490.0	264.5	38974	-4.7	.053	39443
00	17	5.8	340.5	225.4	.988	-.019	1.2	.600	489.8	263.2	38974	-4.9	.054	39445
00	17	6.8	339.8	225.6	1.006	-.001	1.0	.602	488.6	261.9	38974	-5.2	.042	39441
00	17	7.8	340.1	225.7	.999	.002	1.0	.602	488.2	261.8	38974	-5.3	.024	39458
00	17	8.8	341.0	225.7	.998	-.006	1.2	.604	487.4	261.5	38974	-5.4	.047	39440
00	17	9.8	340.6	225.5	.970	-.014	1.2	.605	487.6	262.0	38974	-5.4	.042	39443
00	17	10.7	339.9	225.4	.943	-.014	1.0	.605	489.2	262.2	38965	-5.3	.037	39443
00	17	11.7	339.9	225.5	.941	-.008	1.0	.602	490.0	263.3	39089	-5.2	.043	39449
00	17	12.7	339.9	225.5	.917	-.025	1.0	.604	487.9	261.3	39137	-5.2	.043	39449
00	17	13.8	340.0	225.3	.933	-.030	.9	.604	487.8	261.1	39132	-5.1	.029	39456
00	17	14.7	339.7	225.4	.914	.007	.8	.603	489.3	262.6	39132	-5.3	.039	39456
00	17	15.7	334.7	225.6	.949	.023	.6	.602	489.5	261.9	39132	-5.6	.025	39450
00	17	16.7	332.5	225.6	1.026	-.018	.7	.602	488.7	261.5	39132	-5.8	.041	39448
00	17	17.7	333.8	224.9	1.019	-.026	.9	.601	489.6	261.0	39132	-5.5	.056	39450
00	17	18.7	333.4	225.1	.968	-.005	.9	.602	489.2	261.4	39132	-5.3	.046	39450
00	17	19.7	333.2	225.4	.923	-.003	.9	.602	488.6	260.5	39132	-5.3	.047	39448
00	17	20.7	333.2	225.3	.957	.012	.8	.599	492.7	263.2	39132	-5.4	.032	39453
00	17	21.7	333.1	225.3	.960	-.003	.8	.598	492.2	263.5	39132	-5.4	.039	39452
00	17	22.7	333.7	224.7	.969	-.012	.8	.600	490.5	263.0	39132	-5.4	.053	39454
00	17	23.8	334.0	224.5	.938	-.018	.7	.602	490.1	262.3	39132	-5.0	.032	39454
00	17	24.7	335.4	224.7	.991	-.007	.7	.582	493.7	267.2	39132	-5.1	.043	39458
00	17	25.7	331.9	224.8	.973	.003	.6	.582	486.8	266.3	39132	-5.1	.032	39452
00	17	26.7	330.9	224.6	1.017	-.032	.7	.500	487.0	267.4	39132	-5.1	.056	39453
00	17	27.7	331.2	224.5	.924	.011	.6	.460	484.2	266.4	39132	-4.9	.036	39455
00	17	28.8	350.7	225.5	.993	.020	.8	.560	484.8	265.3	39132	-5.4	.037	39451
00	17	29.7	330.3	225.1	.976	-.015	.6	.596	496.5	268.8	39132	-5.9	.043	39455
00	17	30.7	330.4	225.9	1.049	-.036	.9	.599	487.6	265.7	39132	-5.1	.012	39446
00	17	31.7	330.6	225.4	1.084	-.004	.9	.602	479.8	261.1	39132	-4.0	.020	39449
00	17	32.7	330.3	225.8	1.000	.026	.8	.595	490.0	267.4	39132	-4.3	.003	39462
00	17	33.8	329.6	224.6	1.009	.007	.9	.592	483.1	264.2	39132	-4.9	.010	39455
00	17	34.7	329.2	224.5	1.009	-.014	.9	.599	479.0	263.5	39132	-5.0	.011	39450
00	17	35.7	328.8	224.3	.973	-.016	.8	.602	479.7	262.4	39132	-5.1	.004	39459
00	17	36.7	327.3	224.5	.966	.011	.9	.602	478.7	262.0	39132	-5.0	.008	39457
00	17	37.7	323.1	224.6	1.003	-.024	.9	.602	476.1	260.8	39132	-5.4	.033	39457
00	17	38.8	321.6	224.1	.946	-.033	.9	.603	475.6	260.7	39132	-5.2	.005	39468
00	17	39.7	321.7	224.8	.928	-.003	1.0	.604	474.4	259.7	39132	-5.2	.006	39471
00	17	40.7	322.8	225.9	.949	.001	.9	.603	472.0	258.8	39132	-5.9	.013	39469
00	17	41.7	322.5	226.2	.990	-.011	.9	.603	469.7	257.3	39132	-6.5	.026	39471
00	17	42.7	321.8	226.3	.958	-.003	.9	.603	471.1	258.6	39132	-6.5	.019	39472
00	17	43.8	321.3	226.6	.935	.010	.9	.603	469.5	257.2	39132	-6.4	.011	39473
00	17	44.7	321.3	226.6	1.031	-.022	1.0	.604	470.2	257.7	39132	-6.5	.024	39470
00	17	45.7	320.9	226.4	.945	-.034	.8	.604	471.5	258.8	39132	-6.2	.013	39478
00	17	46.7	319.8	226.7	.951	.047	.9	.604	471.2	260.8	39132	-6.0	.029	39477
00	17	47.7	315.8	227.3	.930	-.025	.9	.604	470.7	258.4	39132	-6.4	.023	39477
00	17	48.8	323.3	226.6	.942	-.062	1.0	.605	470.2	256.9	39132	-5.7	.020	39482
00	17	49.7	335.2	226.4	.965	-.024	.8	.606	471.9	258.0	39132	-5.0	.010	39487
00	17	50.7	333.6	227.5	.950	.004	.7	.604	471.2	257.9	39132	-5.5	.039	39481
00	17	51.7	333.1	228.1	1.049	-.011	.8	.604	470.2	257.7	39132	-6.6	.009	39475
00	17	52.7	333.2	227.7	.979	-.016	.6	.605	472.1	259.5	39132	-6.3	.022	39479
00	17	53.8	332.3	227.7	.997	-.012	.6	.605	471.5	258.9	39132	-5.9	.031	39482
00	17	54.7	332.0	228.0	.975	-.005	.6	.605	471.0	259.0	39132	-6.1	.014	39480
00	17	55.7	331.8	228.3	.929	-.011	.5	.605	471.8	259.8	39132	-6.3	.019	39481
00	17	56.7	331.3	228.3	.891	-.002	.7	.604	470.8	258.8	39132	-6.3	.018	39484
00	17	57.7	330.8	228.3	.835	-.015	.6	.604	465.9	255.5	39132	-6.2	.014	39484
00	17	58.8	330.6	228.3	.971	-.006	.6	.605	464.7	255.6	39132	-6.2	.037	39484
00	17	59.7	330.6	228.3	1.009	.016	.4	.605	476.0	260.1	39132	-6.2	.016	39480
00	17	60.7	330.3	228.3	.957	-.020	.3	.605	474.7	257.1	39132	-6.3	.010	39475

Figure 13. -Continued

HR	MI	SEC	ROLL DEG	ATTACK DEG	PS MBARS	AMACH	SATD DEG C	IAS KNTS	POT DEG K	TAS1 KNTS	RIDE QUALITY
00	17	1.8	0.0	-.9	192.4	.842	-53.9	259.4	400.8	485.3	2
00	17	2.8	.2	-.6	192.4	.843	-53.4	260.0	401.9	486.8	2
00	17	3.8	-.0	-1.0	192.4	.841	-53.7	250.3	401.2	485.4	2
00	17	4.8	-.0	-.8	192.4	.840	-53.7	261.5	402.0	489.0	2
00	17	5.8	-.2	-.5	192.3	.852	-53.5	262.8	402.9	491.5	2
00	17	6.8	-.4	-.5	192.4	.846	-53.6	260.8	401.9	488.0	2
00	17	7.8	-.2	-.6	192.4	.845	-53.6	260.0	401.6	486.7	2
00	17	8.8	-.4	-.6	192.4	.842	-53.5	259.7	401.7	486.2	2
00	17	9.8	-.4	-1.0	192.4	.844	-53.7	260.1	401.6	486.7	2
00	17	10.7	-.1	-.7	192.4	.846	-53.7	260.9	401.8	488.1	2
00	17	11.7	-.2	-.6	192.3	.849	-53.8	261.8	402.0	489.4	2
00	17	12.7	-.0	-.3	192.3	.846	-53.8	260.9	401.7	487.9	2
00	17	13.8	-.4	-.5	192.2	.845	-53.9	260.4	401.3	487.1	2
00	17	14.7	-.1	-.3	192.2	.847	-53.8	261.3	401.8	488.6	2
00	17	15.7	.0	-.8	192.3	.846	-53.3	260.7	402.5	488.3	3
00	17	16.7	-.2	-.8	192.3	.844	-53.3	260.3	402.4	487.6	4
00	17	17.7	-.3	-.6	192.3	.845	-53.6	260.7	401.9	487.8	4
00	17	18.7	-.1	-.6	192.3	.845	-53.6	260.6	401.9	487.6	4
00	17	19.7	.0	-.9	192.3	.844	-53.5	260.2	402.0	487.1	4
00	17	20.7	-.0	-1.1	192.3	.848	-53.5	261.6	402.5	489.5	4
00	17	21.7	.1	-.4	192.3	.850	-53.4	262.3	402.9	490.8	4
00	17	22.7	.0	-.5	192.3	.849	-53.5	261.9	402.6	490.0	4
00	17	23.8	-.0	-.3	192.3	.849	-53.7	261.9	402.2	489.8	4
00	17	24.7	.2	-.5	192.2	.854	-53.5	263.7	403.2	493.0	4
00	17	25.7	.1	-1.0	192.3	.857	-53.2	264.7	404.0	494.9	4
00	17	26.7	-.7	-.4	192.3	.863	-53.4	267.0	404.6	498.5	4
00	17	27.7	-.6	-.8	192.2	.864	-53.1	267.2	405.1	499.1	4
00	17	28.8	-.1	-.7	192.3	.855	-52.7	263.8	404.7	494.1	4
00	17	29.7	.6	-1.6	192.2	.859	-52.4	265.2	405.8	496.8	4
00	17	30.7	-.5	-1.0	192.3	.861	-52.7	266.2	405.4	498.0	4
00	17	31.7	-.3	-.2	192.3	.854	-53.2	263.6	403.7	493.1	4
00	17	32.7	.1	-.5	192.2	.855	-53.3	264.0	403.8	493.9	4
00	17	33.8	-.1	-.6	192.2	.855	-53.2	263.8	403.8	493.5	3
00	17	34.7	-1.4	-.6	192.3	.849	-53.3	262.1	403.0	490.5	3
00	17	35.7	-.9	-.6	192.2	.849	-53.7	262.0	402.2	490.0	5
00	17	36.7	1.1	-1.0	192.2	.847	-53.7	261.1	401.9	488.4	5
00	17	37.7	1.3	-.4	192.2	.844	-54.0	260.3	401.2	486.9	5
00	17	38.8	1.6	-.1	192.1	.847	-54.8	261.0	399.9	487.1	5
00	17	39.7	3.6	-.5	192.1	.845	-55.1	260.5	399.4	486.2	5
00	17	40.7	4.7	-.7	192.1	.839	-55.0	258.3	398.8	482.6	5
00	17	41.7	4.6	-.3	192.1	.835	-55.1	256.9	398.0	480.1	5
00	17	42.7	5.0	-.5	192.1	.835	-55.4	256.9	397.6	479.8	5
00	17	43.8	5.5	-.6	192.1	.834	-55.4	256.5	397.4	479.1	5
00	17	44.7	4.9	-.6	192.1	.832	-55.5	255.8	397.0	477.9	5
00	17	45.7	4.1	-.5	192.0	.839	-56.3	258.4	396.5	481.4	5
00	17	46.7	6.1	-1.7	192.0	.841	-55.2	258.9	398.6	483.3	5
00	17	47.7	5.4	-.7	192.0	.835	-54.2	257.0	399.8	481.3	5
00	17	48.8	2.3	-.1	192.0	.836	-54.9	257.3	398.6	481.1	5
00	17	49.7	3.1	-.5	192.0	.840	-55.2	258.6	398.5	483.0	5
00	17	50.7	3.9	-1.0	192.0	.837	-54.8	257.7	398.9	481.9	5
00	17	51.7	2.6	-.7	192.1	.832	-55.1	255.9	397.7	478.4	5
00	17	52.7	1.8	-.6	192.0	.837	-56.4	257.6	396.0	480.0	5
00	17	53.8	2.0	-.6	192.0	.840	-56.5	258.6	396.2	481.0	5
00	17	54.7	1.8	-.6	192.0	.836	-56.2	257.4	396.3	479.8	5
00	17	55.7	1.1	-.6	192.0	.839	-56.7	258.2	395.7	480.6	5
00	17	56.7	.7	-.6	192.0	.840	-56.7	258.6	395.8	481.2	5
00	17	57.7	.5	-1.0	192.0	.834	-56.0	256.3	396.3	478.3	5
00	17	58.8	.1	-.7	192.0	.829	-55.6	254.9	396.6	476.4	5
00	17	59.7	.4	-.6	192.0	.833	-54.9	256.1	398.3	479.1	5
00	17	60.7	.4	-.9	192.1	.834	-54.4	256.7	399.3	480.5	5

Figure 13. -Continued

LABEL	PARAMETER	UNITS
HR MI SEC	GMT	Hours Minutes Seconds
PA	Differential Pressure	Millibars
IR	Infrared	ARIS Counts (Not Expressed in Engineering Units)
TAT	Total Air Temperature	Degrees Celsius
LAC	Lateral Acceleration (Tail)	G
VAC	Vertical Acceleration (Tail)	G
MRI	UITS Rating	"R" Units
ILAT	Latitude	Degrees North
ILON	Longitude	Degrees West (West-Minus; East-Plus)
GSI	Ground Speed	Knots
TRACK	Track Angle	Degrees
THI	True Heading	Degrees
WSI	Wind Velocity	Knots
WDI	Wind Direction	Degrees
MHF	Magnetic Heading	Degrees
F VAC	Vertical Acceleration (c.g.)	G
F LAC	Lateral Acceleration (c.g.)	G
PITCH	Pitch Angle	Degrees
MACH	Mach	Decimal Fraction
TAS	True Airspeed	Knots
CAS	Computed Airspeed	Knots
ALT CRS	Coarse Altitude	Feet
DA	Drift Angle	Degrees
LON ACC	Longitudinal Acceleration (c.g.)	G
ALT	Fine Altitude	Feet
ROLL	Roll Angle	Degrees
ATTACK	Angle of Attack	Degrees
PS	Static Pressure (Computed)	Millibars
AMACH	Mach Number (Computed)	Decimal Fraction
SATD	Static Air Temperature (Computed)	Degrees Celsius
IAS	Indicated Airspeed (Computed)	Knots
POT	Potential Temperature (Computed)	Degrees Kelvin
TAS 1	True Airspeed (Computed)	Knots
RIDE	Ride Quality Rating	Quality

Figure 14. Parameters and Units Associated with Each Column Heading Shown in Figure 13.

Samples of the analog traces taken from the digital data are shown in Figures 15, 16, 17, and 18. The traces shown are copies of the printouts for the two (2) single axis accelerometers mounted in the tail of the aircraft, the UITS "R" rating, and static air temperature.

An analysis of meteorological conditions associated with the turbulence event indicated that a sharp upper trough oriented NNE-SSW near Las Vegas was responsible for generating the CAT. The B-747 encountered turbulence while cruising at 11.9 km (39,000 feet) in clear skies on a flight from Chicago to Los Angeles.

Examination of the accelerometer traces revealed that a period of significant excitation began at 16 minutes and 30 seconds after 24 hours (0000Z). The data taken by the meteorological observer on this particular flight indicated that light clear air turbulence began at 0017Z and increased to moderate within one (1) minute. The UITS "R" rating trace registered a maximum value of 7.7 during this same time period. It was also noted that the NASA observer rated the ride quality as "very uncomfortable". The exact time at which the NASA observer changed his ride quality rating can be seen by examining the digital data (Ride Quality rating of "5" initiated at 0017:35Z).

Static air temperature also displayed a significant change beginning at 0016:30Z. A total change of four (4) degrees Celsius in one minute occurred at the same time the turbulence began the initial increase in intensity. Temperature fluctuations of up to 4.5°C continued during the turbulence encounter. Stabilization of the temperature trace began just before 0020Z. However, the pilot received a clearance from Air Route Traffic Control and began a descent at 0019:00Z to avoid further rough air. The remainder of the temperature trace indicates the warming that occurred during the descent below 11.9 km.

This preliminary analysis of a small sample of the recorded parameters indicates that a great deal of useful information may be acquired from a detailed and comprehensive examination of all the data.

FLIGHT SUMMARIES

Information on meteorological and flight conditions that were encountered on each of the 57 data collection flights as well as remarks on the status of the research equipment is

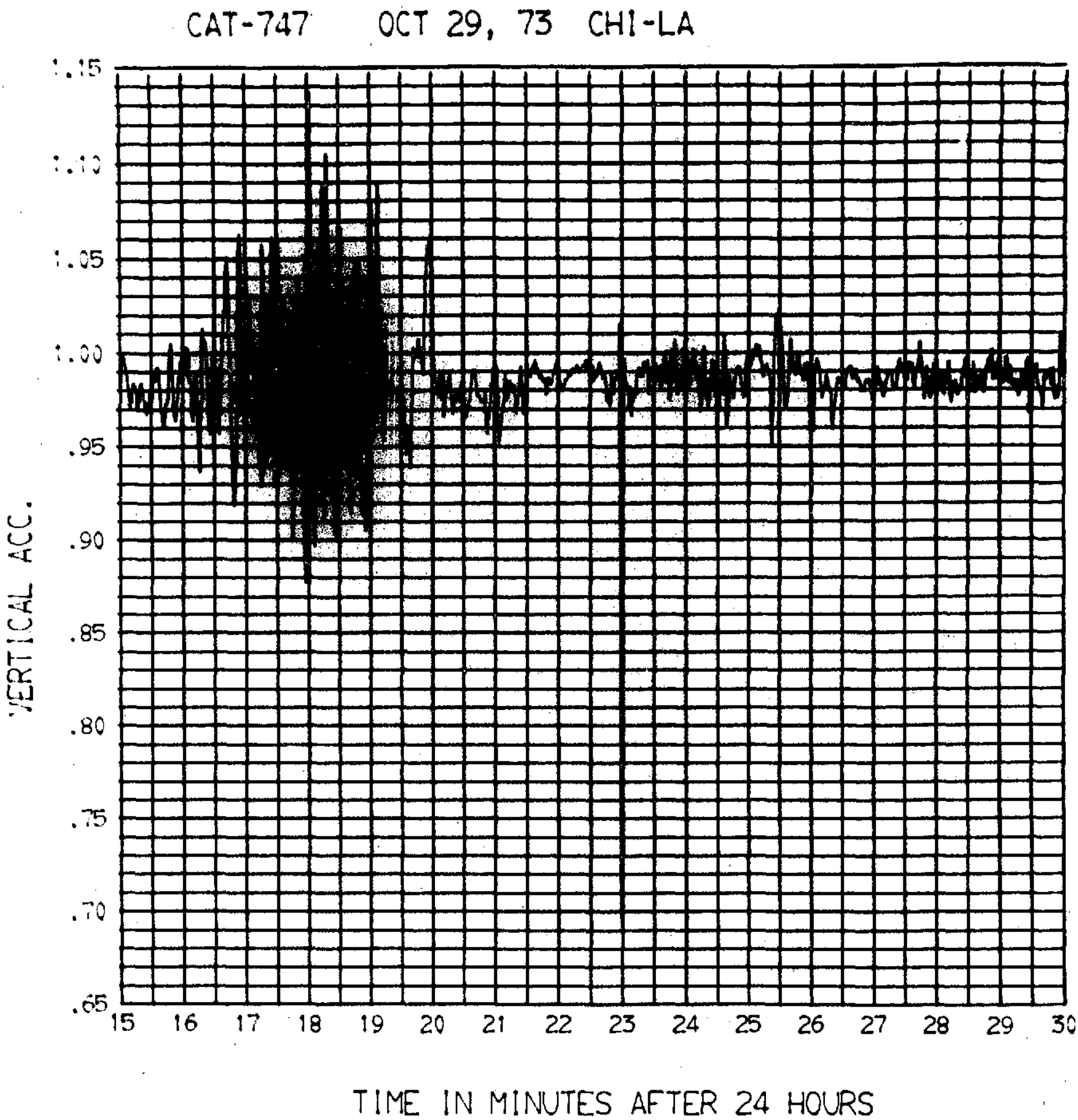

Figure 15. Analog Traces of Tail Mounted Vertical Accelerometer Taken From One Second Average of Digital Data.

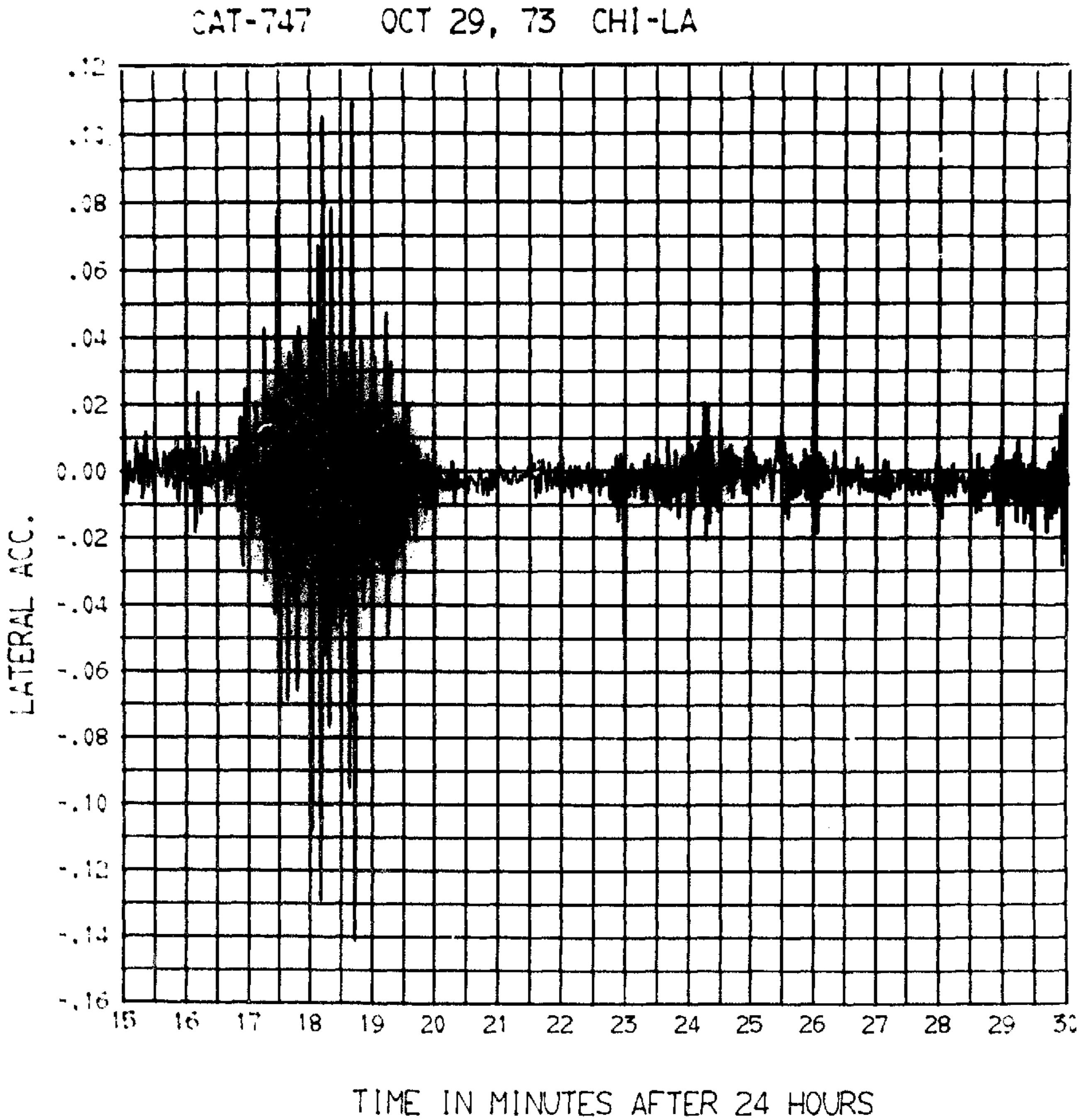

Figure 16. Analog Traces of Tail Mounted Lateral Accelerometer Taken From One Second Average of Digital Data.

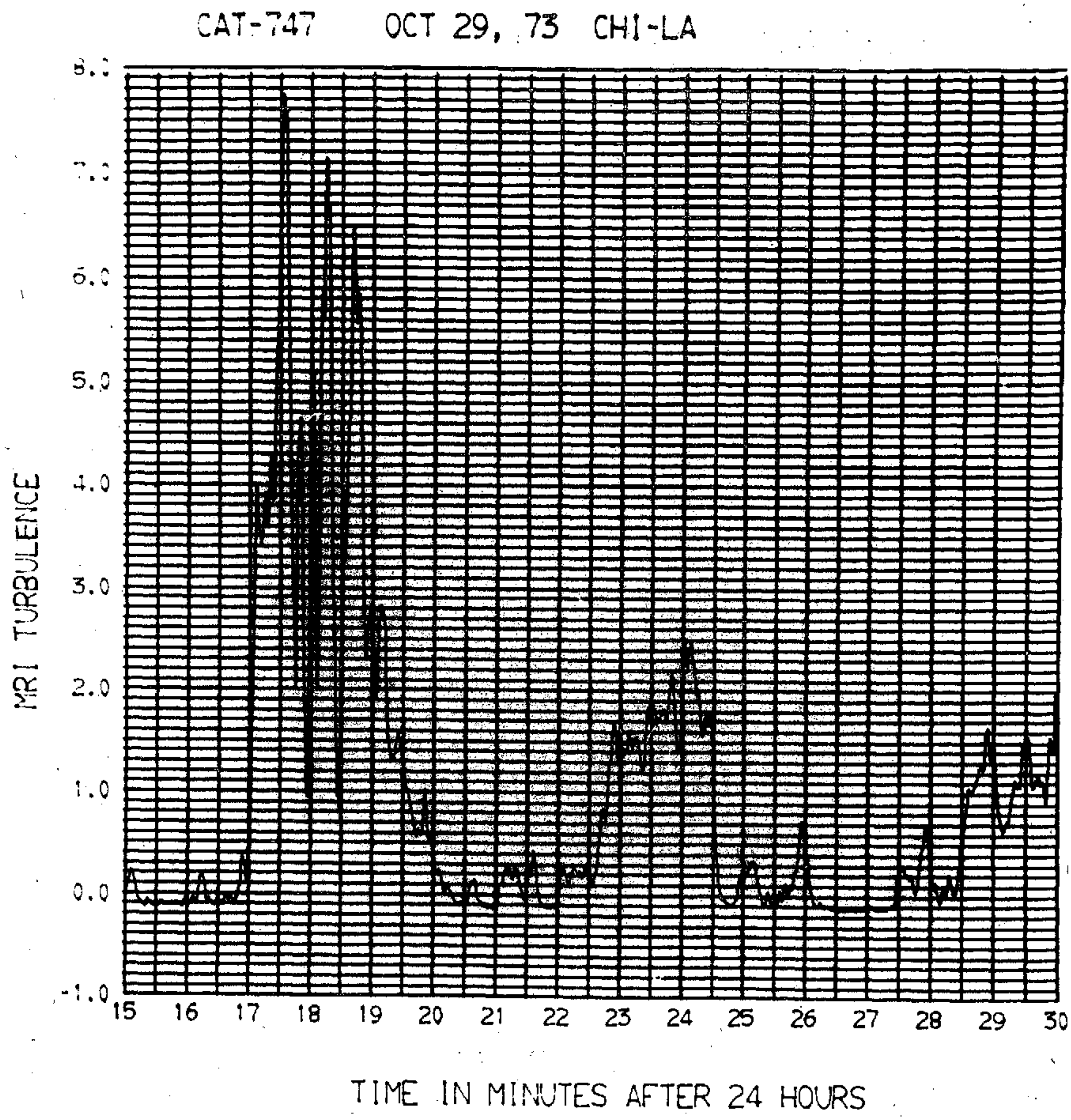

Figure 17. Analog Traces of Meteorology Research, Inc., UITS "R" Rating Taken From One Second Average of Digital Data.

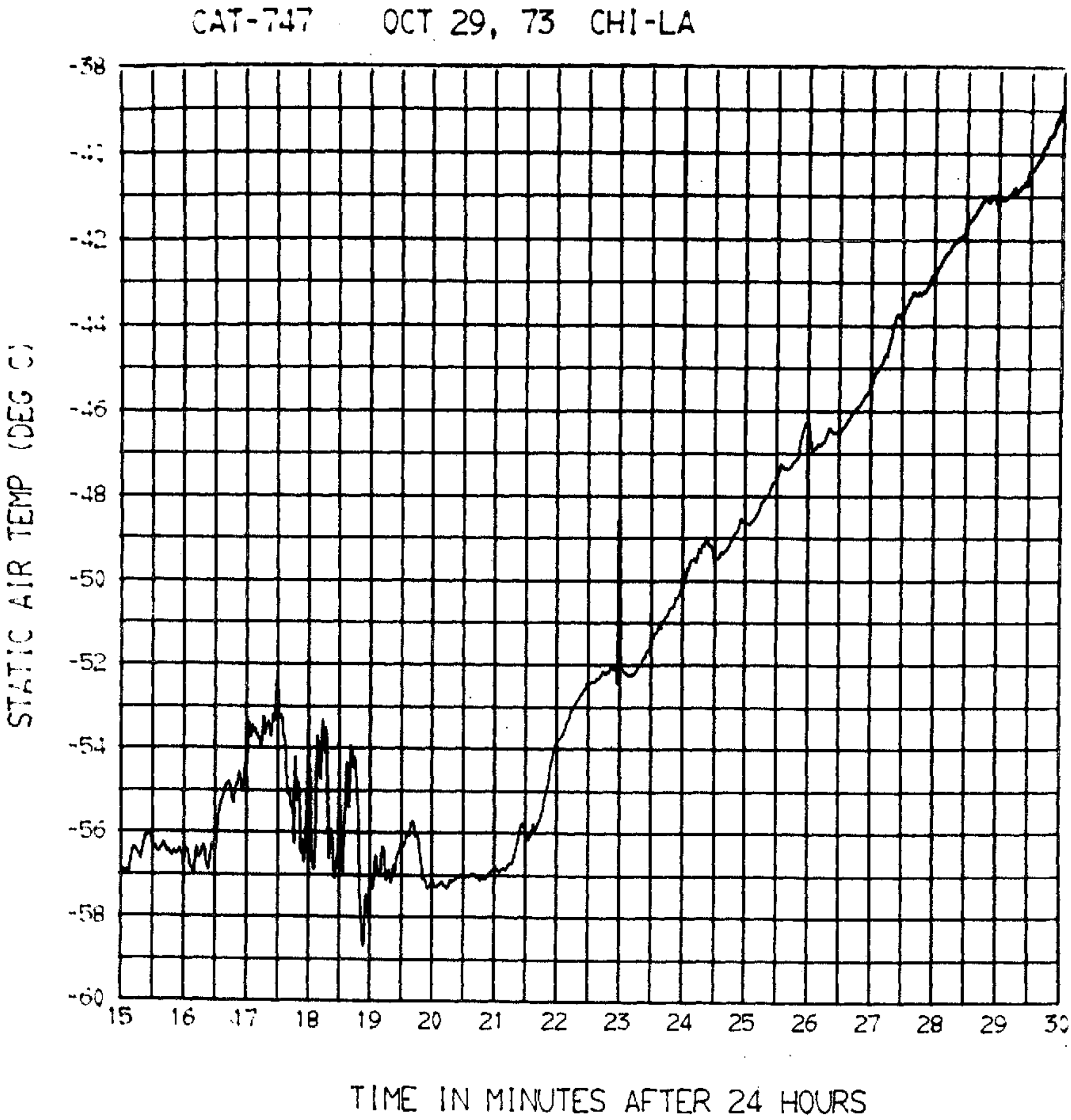

Figure 18. Analog Traces of Static Air Temperature Taken From One Second Average of Digital Data.

provided in Table I. The General Flight Conditions and Remarks section includes a brief description of the upper air meteorological situation at the time of the flight as well as comments on the status of various sensors and instruments, when appropriate. Also included in the table is the subjective evaluation by the meteorological observer of the highest turbulence intensity that was experienced on each flight. This evaluation was in addition to his observations of the highest "R" units on the UITS meter and the NASA passenger's ride quality ratings that were displayed as a series of binary lights on the Signal Conditioning Unit. However, the UITS meter was not a multiple pointer indicator capable of displaying highest maximum as well as the continuous instantaneous indication of "R" units. Therefore, the maximum "R" units listed in the table may not coincide exactly with the recorded UITS data.

Comments on sky conditions in the turbulent area of the altitude of the flight were also added to the "Highest Observed UITS 'R' Value" column. A complete history of sky conditions above, at and below the aircraft for the entire route was included in the horizontal and vertical cross sections prepared by the meteorological observer on each flight.

CONCLUDING REMARKS

The principal objective of this program was to acquire in-flight data on a large wide-bodied commercial airliner to support the ride quality program of the NASA Flight Research Center. This requirement was satisfied with the successful completion of 57 data collection flights. Since quantitative data have not been analyzed, any conclusions made at this time would be incomplete. However, preliminary analysis indicates that the recorded aircraft and atmospheric data may contribute knowledge regarding the formation and life cycle of atmospheric motions that affect an aircraft during flight. Therefore, it is anticipated that scientists and engineers with various and diversified interests may effectively utilize this information to expand their knowledge of the response of an aircraft to its environment.

TABLE I

SUMMARY OF DATA COLLECTION FLIGHTS

DATA FLIGHT NO.	GENERAL FLIGHT CONDITIONS AND REMARKS	HIGHEST OBSERVED UITS "R" VALUE (MET OBSVR EVAL)	HIGHEST OBSERVED RIDE QUALITY RATING
1	Weak trough between 130W and 135W, no jet streams. Missing parameters, tail vertical acceleration, ride quality, angle of attack.	Not available	Not available
2	Major trough over western half of U.S., closed low aloft over Colorado. Missing parameters, tail vertical acceleration, angle of attack.	3.5 in clouds (LGT TURBC)	Not available
3	Major trough over western half of U.S., northerly polar jet over Nevada to Southern California, SW jet over Kansas and Nebraska. Missing parameters, tail vertical acceleration, angle of attack.	4 in clear (LGT TURBC)	Not available
4	Broad ridge over route, entered NW jet just prior to ORD, experienced light to moderate CAT, entire trip in clear. Missing parameters, tail vertical acceleration, angle of attack.	5 in clear (LGT-MDT CHOP)	Not available
5	Generally smooth trip through broad high pressure ridge, entire trip in clear. Missing parameter, angle of attack.	3 in clear (LGT CHOP)	Not available

TABLE I con'd

DATA FLIGHT NO.	GENERAL FLIGHT CONDITIONS AND REMARKS	HIGHEST OBSERVED UITS "R" VALUE (MET OBSVR EVAL)	HIGHEST OBSERVED RIDE QUALITY RATING
6	Westerly jet over Southern California, ridge over Rockies and Plains, entire trip on top of clouds, very light chop in clear. Missing parameters, angle of attack.	2 in clear (VRY LGT CHOP)	4
7	Weak ridge over entire route, westerly jet over Southern California, light occasional moderate turbulence in clear. Missing parameter, angle of attack.	2.5 in clear (LGT-MDT CHOP)	4
8	Trough over eastern Kansas, undercast east of trough, no jet streams, 18 minutes of continuous light chop.	4 in clear (LGT TURBC)	3
9	Trough over eastern Nebraska, light chop in horizontal wind shear area, light turbulence in cirrus bases.	2 in clear (LGT TURBC)	3
10	Sharp trough over Utah, 45 minutes of moderate CAT in trough and SW circulation, lenticular clouds over Rockies, ridge over Plains.	8 in clear (MDT-SVR CAT)	5
11	Moderate occasional severe CAT with horizontal wind shear over southeastern California, 3-4°C temperature change in less than 2 minutes, lenticular clouds below over Denver.	8 in clear (MDT-SVR CAT)	5

TABLE I cont'd

DATA FLIGHT NO.	GENERAL FLIGHT CONDITIONS AND REMARKS	HIGHEST OBSERVED UITS "R" VALUE (MET OBSVR EVAL)	HIGHEST OBSERVED RIDE QUALITY RATING
12	Light to moderate continuous CAT for 25 minutes in northerly jet over Southern California and Arizona, moderate CAT top side of ridge over eastern Kansas.	7 in clear (MDT CHOP)	5
13	Light CAT through trough line over central Nebraska, NW jet stream over Colorado Rockies.	2 in clear (LGT TURBC)	4
14	Generally smooth flight, very light CAT near NWly jet stream over eastern Colorado.	2 in clear (LGT CHOP)	2
15	Generally smooth flight, light CAT near NWly jet stream over eastern Colorado.	2.5 in clear (LGT TURBC)	2
16	General westerly circulation aloft over eastern Pacific, large High cell over entire route at surface, 3 minutes of light chop in clouds.	2.5 in clouds (LGT CHOP)	3
17	Weak trough near 140W, scattered buildups west of trough, light to moderate chop through trough line, in clear.	3 in clear (LGT-MDT CHOP)	4

TABLE I cont'd

DATA FLIGHT NO.	GENERAL FLIGHT CONDITIONS AND REMARKS	HIGHEST OBSERVED UITS "R" VALUE (MET OBSVR EVAL)	HIGHEST OBSERVED RIDE QUALITY RATING
18	In and out of cirrus nearly entire flight, sharp trough just east of Hawaii, SWly flow from trough to mainland, thunderstorms vicinity Hawaii, moderate turbulence vicinity thunderstorms, full scale IR oscillations in clouds.	7 in clouds (MDT TURBC)	5
19	Light turbulence in trough near 150W, CB vicinity, light occasional moderate CAT in horizontal wind shear area near 130W, front approaching Southern California.	3 in clear LGT-MDT CHOP)	4
20	Sharp trough across route between 145W and 150W, 30 minutes of light to moderate chop prior to and entering area of scattered thunderstorms.	3 in clouds (LGT-MDT CHOP)	5
21	Weak trough near 145W, moderate CAT in trough, light CAT on climbout HNL.	2 in clear (MDT CHOP)	5
22	Northerly flow between LAX and 130W, weak southerly flow to 140W, northeast flow 140W to HNL, light CAT in directional shear area.	2 in clear (LGT TURBC)	3
23	In and out of cirrus to 147W, strong easterly flow between 140W and 130W, northerly jet off U.S. west coast, only light turbulence entire trip at cruising altitude, light to moderate turbulence on descent.	2 in clear (LGT TURBC)	3

TABLE I cont'd

DATA FLIGHT NO.	GENERAL FLIGHT CONDITIONS AND REMARKS	HIGHEST OBSERVED UITS "R" VALUE (MET OBSVR EVAL)	HIGHEST OBSERVED RIDE QUALITY RATING
24	Trough near 130W with SWly jet, in clouds west of trough, occasional light turbulence in clouds from 145W to HNL, large IR oscillations in clouds	4 in clouds (LGT TURBC)	5
25	Broad trough between 140W and U.S. west coast, Wly jet in trough, very light CAT in trough, light turbulence in clouds HNL to 150W.	2 in clouds (LGT TURBC)	5
26	Generally smooth to occasional light chop entire flight, ridge over eastern half of route, trough over southwest U.S. TAT probe inoperative.	4 in clear (LGT CHOP)	4
27	High pressure over entire route, light chop in cirrus from HNL to 145W. TAT probe inoperative.	3 in clouds (LGT CHOP)	4
28	Closed low just south of route near 150W, light turbulence in clouds same area, rest of flight generally smooth. TAT probe inoperative.	2.5 in clouds (LGT TURBC)	4
29	Trough line near 150W, light CAT in trough with scattered thunderstorms to south, in tops of cirrus from 132W to 125W. TAT probe inoperative.	3 in clear (LGT TURBC)	4

TABLE I cont'd

DATA FLIGHT NO.	GENERAL FLIGHT CONDITIONS AND REMARKS	HIGHEST OBSERVED UITS "R" VALUE (MET OBSVR EVAL)	HIGHEST OBSERVED RIDE QUALITY RATING
30	Sharp trough just west of Hawaii, light to moderate chop through trough, in and out of cirrus over-cast over eastern half of route through weak ridge.	6.4 in clouds (LGT-MDT CHOP)	4
31	Generally clear flight with only occasional very light chop, light chop during climbout HNL.	2.2 in clear (VRY LGT CHOP)	4
32	Continuous light turbulence in tops and bases of cirrus, westerly to southwesterly flow from LAX to 145W, clear and smooth west of 145W with northerly circulation.	2 in clouds (LGT TURBC)	5
33	Continuous light turbulence in and out scattered cirrus between 130W and 125W, trough over Southern California.	3.5 in and out of clouds (LGT TURBC)	5
34	Continuous light CAT for 15 minutes in northwesterly flow near 125W, dis-sipating front along route, 180^{o} wind shift near 135W.	3.5 in clear (LGT TURBC)	5
35	Scattered TCU and CB north of route near 150W, NWly flow near 150W, SWly flow near 140W, southerly flow near 130W in broad trough, generally smooth flight.	2.5 in clear (LGT CHOP)	4

TABLE I cont'd

DATA FLIGHT NO.	GENERAL FLIGHT CONDITIONS AND REMARKS	HIGHEST OBSERVED UITS "R" VALUE (MET OBSVR EVAL)	HIGHEST OBSERVED RIDE QUALITY RATING
36	Generally smooth at altitude, on top of clouds, light chop in cumulus on letdown HNL.	3 in clear (LGT CHOP)	3
37	Broad trough between HNL and 140W, light CAT between 153W and 146W, rest of flight generally smooth including through CB activity near 144W.	3 in clear (LGT TURBC)	3
38	Trough at 135W, entire trip in clear, light chop near trough.	2.5 in clear (LGT CHOP)	3
39	Northwesterly flow entire trip, just under cirrus overcast between 140W and 130W, in and out of cirrus near 125W, occasional very light chop entire flight.	3 in cirrus bases (LGT CHOP)	4
40	Two hours of light chop with occasional moderate in strong NWly polar jet, light chop in cirrus tops, trough near 130W.	5 in tops cirrus (LGT-MDT CHOP)	4
41	Brief moderate chop with 13°C temperature change crossing apparent frontal structure vicinity 130W. Broken wire in rating box connector.	6.8 in clear (MDT CHOP)	Not available
42	Smooth to very light chop entire flight, in and out cirrus from Rockies to western Iowa. Ride quality rating box inoperative.	Not available	Not available

TABLE I cont'd

DATA FLIGHT NO.	GENERAL FLIGHT CONDITIONS AND REMARKS	HIGHEST OBSERVED UITS "R" VALUE (MET OBSVR EVAL)	HIGHEST OBSERVED RIDE QUALITY RATING
43	Broad ridge over western half U.S., smooth to very light chop entire route. Ride quality rating box inoperative.	Not available	Not available
44	Northeasterly circulation from 135W to HNL, occasional light CAT entire trip, light occasional moderate CAT with directional wind shear near 140W.	7.5 in clear (MDT TURBC)	5
45	Generally clear and smooth flight, two minutes of light chop in directional wind shear, continuous light chop in cirrus bases near 125W.	3 in clear (LGT TURBC)	4
46	Generally smooth flight with only occasional light chop, northeasterly flow 140W to HNL. Intermittent signal loss from ride quality rating box.	2.5 in clear (LGT CHOP)	3
47	Generally smooth flight with only occasional very light chop. Intermittent signal loss from ride quality rating box.	0.5 in clear (VRY LGT CHOP)	2
48	Clear and smooth most of flight, light chop in tops of cirrus and vicinity scattered thunderstorms just east of Hawaii, jet stream well north of route.	3.4 in clear on top cirrus (LGT CHOP)	5

TABLE I cont'd

DATA FLIGHT NO.	GENERAL FLIGHT CONDITIONS AND REMARKS	HIGHEST OBSERVED UITS "R" VALUE (MET OBSVR EVAL)	HIGHEST OBSERVED RIDE QUALITY RATING
49	Thunderstorms and layered clouds on climbout HNL, generally clear and smooth east of 150W, wind velocity shear off California coastline.	4 in clear (LGT CHOP)	5
50	Clear skies from LAX to 135W, in thin cirrus bases 145W to 150W, overcast cirrus above from 135W to HNL, NWly jet stream across route at 130W, smooth-very light chop entire flight.	4 in clear (LGT CHOP)	5
51	Intermittent light chop in and out of cirrus HNL to 142W, cold front across route at 130W, light CAT prior to frontal zone.	3 in clear (LGT CHOP)	4
52	In cirrus overcast 130W to 152W, light chop 150W to 152W with scattered CB vicinity.	5 in clouds (LGT CHOP)	4
53	West half of route on south side of a E-W trough, polar jet on route from 135W to 125W, entire trip in and out thin cirrus with intermittent light chop.	4 in clouds (LGT CHOP)	4
54	Flight mostly in clouds, sharp trough just east of Hawaii, continuous light occasional moderate chop in clouds with wind shift in trough.	4.8 in and out clouds (LGT-MDT CHOP)	2

TABLE I cont'd

DATA FLIGHT NO.	GENERAL FLIGHT CONDITIONS AND REMARKS	HIGHEST OBSERVED UITS "R" VALUE (MET OBSVR EVAL)	HIGHEST OBSERVED RIDE QUALITY RATING
55	Trough near 140W, in cirrus tops east of 140W, clear west of 140W, light chop in cloud tops with 3°C temperature drop in 30 seconds.	3 in cloud tops (LGT CHOP)	2
56	Half of flight in clouds, light chop in clouds, scattered buildups south of course near 140W, NWly jet stream across route at 130W.	5.5 in tops cirrus (LGT-MDT CHOP)	4
57	In and out of clouds on top of under-cast most of flight, moderate tur-bulence in cloud tops with scattered buildups south of route near 140W, NWly polar jet across route at 145W.	7.5 in cloud tops (MDT TURBC)	5

APPENDIX

DATA COLLECTION FLIGHTS FOR RIDE QUALITY AND ATMOSPHERIC TURBULENCE RESEARCH

DATA FLT. NO.	GMT DATE	CAL FLT. NO.	ROUTE	TIME (Z) OFF - ON
1	9/28/73	608	HNL-LAX	0840Z-1325Z
2	10/11/73	608	LAX-ORD	1530Z-1840Z
3	10/11/73	903	ORD-LAX	2015Z-2345Z
4	10/13/73	608	LAX-ORD	1527Z-1845Z
5	10/13/73	903	ORD-LAX	2014Z-2346Z
6	10/20/73	608	LAX-ORD	1528Z-1844Z
7	10/20/73	903	ORD-LAX	2007Z-2339Z
8	10/27/73	608	LAX-ORD	1536Z-1912Z
9	10/27/73	903	ORD-LAX	2025Z-2341Z
10	10/29/73	608	LAX-ORD	1627Z-2005Z
11	10/29/73	903	ORD-LAX	2117Z-0049Z/30
12	10/30/73	608	LAX-ORD	1725Z-2043Z
13	10/30/73	903	ORD-LAX	2207Z-0135Z/31
14	10/31/73	608	LAX-ORD	1631Z-1945Z
15	10/31/73	903	ORD-LAX	2241Z-0230Z/1
16	11/6/73	607	LAX-HNL	2103Z-0200Z/7
17	11/7/73	600	HNL-LAX	1913Z-2358Z
18	11/12/73	607	LAX-HNL	2055Z-0236Z/13
19	11/14/73	602	HNL-LAX	0055Z-0535Z
20	11/14/73	607	LAX-HNL	2047Z-0207Z/15

APPENDIX
(cont'd)

DATA FLT. NO.	GMT DATE	CAL FLT. NO.	ROUTE	TIME (Z) OFF - ON
21	11/16/73	602	HNL-LAX	0045Z-0523Z/17
22	11/23/73	607	LAX-HNL	2043Z-0133Z/24
23	11/25/73	602	HNL-LAX	0046Z-0548Z
24	11/29/73	607	LAX-HNL	2058Z-0221Z/30
25	12/1/73	602	HNL-LAX	0113Z-0542Z
26	12/3/73	607	LAX-HNL	2053Z-0145Z/4
27	12/5/73	602	HNL-LAX	0044Z-0527Z
28	12/5/73	607	LAX-HNL	2057Z-0159Z/6
29	12/6/73	600	HNL-LAX	1927Z-0021Z/7
30	12/10/73	607	LAX-HNL	2048Z-0152Z/11
31	12/12/73	602	HNL-LAX	0048Z-0527Z
32	12/12/73	607	LAX-HNL	2117Z-0224Z/13
33	12/13/73	600	HNL-LAX	1921Z-0015Z/14
34	12/14/73	605	LAX-HNL	0259Z-0807Z
35	12/14/73	600	HNL-LAX	1925Z-0014Z/15
36	12/17/73	605	LAX-HNL	0309Z-0820Z
37	12/17/73	600	HNL-LAX	1907Z-2339Z
38	12/19/73	605	LAX-HNL	0315Z-0820Z
39	12/19/73	600	HNL-LAX	1913Z-2351Z
40	12/21/73	605	LAX-HNL	0321Z-0826Z
41	12/21/73	600	HNL-LAX	1908Z-0005Z/22

APPENDIX
(cont'd)

DATA FLT. NO.	GMT DATE	CAL FLT. NO.	ROUTE	TIME (Z) OFF - ON
42	12/22/73	908	LAX-ORD	2014Z-2322Z
43	12/23/73	919	ORD-LAX	0052Z-0442Z
44	12/27/73	605	LAX-HNL	0259Z-0738Z
45	12/27/73	600	HNL-LAX	1926Z-0016Z/28
46	12/28/73	605	LAX-HNL	0325Z-0808Z
47	12/29/73	602	HNL-LAX	0043Z-0531Z
48	12/29/73	607	LAX-HNL	2131Z-0232Z/30
49	12/31/73	602	HNL-LAX	0107Z-0556Z
50	1/2/74	607	LAX-HNL	2118Z-0232Z/3
51	1/3/74	600	HNL-LAX	1918Z-0003Z/4
52	1/5/74	607	LAX-HNL	2119Z-0242Z/6
53	1/7/74	602	HNL-LAX	0010Z-0451Z
54	1/7/74	607	LAX-HNL	2043Z-0159Z/8
55	1/9/74	602	HNL-LAX	0018Z-0458Z
56	1/8/74	603	LAX-HNL	1740Z-2303Z
57	1/10/74	7608	HNL-LAX	0841Z-1325Z

REFERENCES

1. Kadlec, Paul W.: Atmospheric Temperature Gradients Related to Clear Air Turbulence in the Upper Troposphere and Lower Stratosphere. NASA CR-91055, November, 1967.

2. Jones, D. N.: "An Investigation of a Vertically Scanning Infrared Radiometer as a Clear Air Turbulence Warning System", Final Report, Contract No. F19628-72-C-0086, Air Force Cambridge Research Laboratories, December, 1972.

3. Kadlec, Paul W.: Survey of Clear Air Turbulence Detection Methods. AIAA paper presented at the USSR/US Symposium and Technical Display on Aeronautical Technology, Moscow, 1973.

4. Flint, E. F.: Description of IDIS-5X1A Infrared Sensor. Rockwell International, Autonetics Division, February, 1974.

BIBLIOGRAPHY

Airmans Information Manual, Basic Flight Manual and ATC Procedures, Federal Aviation Administration, Washington, D. C., May, 1974.

Boeing 747 Maintenance Manual: ATA Chapter 27 & 34. The Boeing Company, Seattle, Washington, 1973.

Meteorology Research, Inc., Instruction Manual: Universal Indicated Turbulence System, Model 1120. Meteorology Research, Inc., Altadena, California, July, 1969.

Systron Donner Specification Manual: Model 4310 Accelerometer. Systron Donner Corporation, Concord, California, November, 1965.

Teledyne Controls Maintenance Manual 31-31-00: Flight Data Acquisition and Recording System, Model No. 70-200. Teledyne Controls, El Segundo, California, December 1, 1971.