NASA TECHNICAL MEMORANDUM

NASA TM X-1234

NASA TM X-1234

OPERATIONAL REPORT ON THE NASA 1965 AIRBORNE SOLAR ECLIPSE EXPEDITION

by Michel Bader, Louis C. Haughney, Glen W. Stinnett, And Richard A. Acken

Ames Research Center
Moffett Field, Calif.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION – WASHINGTON, D.C. – MAY 1966

NASA TM X-1234

OPERATIONAL REPORT ON THE NASA 1965 AIRBORNE SOLAR ECLIPSE EXPEDITION

By Michel Bader, Louis C. Haughney, Glen W. Stinnett,
and Richard A. Acken

Ames Research Center
Moffett Field, Calif.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

For sale by the Clearinghouse for Federal Scientific and Technical Information
Springfield, Virginia 22151 - Price $3.00

TABLE OF CONTENTS

OPERATIONAL REPORT ON THE NASA 1965 AIRBORNE

SOLAR ECLIPSE EXPEDITION

By Michel Bader, Louis C. Haughney, Glen W. Stinnett,
and Richard A. Acken

Ames Research Center

SUMMARY

The third longest total solar eclipse of this century occurred on 30 May 1965. The path of totality started in New Zealand at sunrise, curved northeast to just above the equator, then down to the west coast of Peru at sunset. The point of maximum duration of totality, $5^m\ 20^s.4$, was at $2^\circ\ 05'.7$ S, $132^\circ\ 57'.7$ W. The sun's elevation at that point was 65°.

NASA modified a CV-990 four-engine jet transport to provide an observation platform over the South Pacific Ocean for 13 experiments. Thirteen cut-outs were made at a 650 elevation in the fuselage and fitted with optical quality windows. Converters were installed to provide 14 kVA of 60 c/s power, and junction boxes were spaced along the cabin to bring this and the normal 400 c/s aircraft power for experimenter use. Digital timing signals synchronized to radio stations WWV and WWVH were provided.

The navigation was performed with a periscopic sextant, and the aircraft position was updated by a tracking ship about an hour before totality intercept. Aircraft speed lengthened the available totality time to $9^m\ 42^s$. The total flight time was $8^h\ 22^m$ from the Hilo, Hawaii, base to intercept and, thence, to Papeete, Tahiti, for refueling. Aircraft stability was within ±1/4°. Aircraft heading was kept within ±1/2° of nominal (90° to the sun line) with the help of a specially designed autopilot control and sun compass.

HISTORY AND LOGISTICS

Aircraft have been used sporadically for astronomical research in the past. For example, the annular eclipse of 8-9 May 1948 was observed by two B-29 airplanes near the Aleutian Islands on 8 May (just east of the International Date Line). Their observing time was 24 seconds, and they had to climb to 29,000 feet to get above the weather. A fascinating account of this expedition and the concurrent ground-based editions is given in reference 1. Although different in particulars, problems encountered in 1948 were strikingly similar to those experienced in 1965: organization, coordination, communications, remote and primitive foreign bases, weather, navigation, instrumentation. The 1948 effort was hailed as "a new high in coordinated scientific endeavor" and "a historic . . . testing of a trail-blazing aerial technique for astronomical research" (ref. 1). It was anticipated that "Perhaps the day may come when major scientific organizations . . . will

maintain their own specially equipped aircraft for various phases of celestial research and other projects of exploration . . ."

Since then, occasional uses have been made of aircraft for astronomical purposes, and several aircraft have been converted into permanent flying laboratories for other than astronomical or aeronautical research. Impetus for use of a large jet transport for astronomical studies came from the use of a Douglas DC-8 to observe the solar eclipse of 20 July 1963, under the leadership of the late Dr. W. B. Klemperer (ref. 2).

In October 1964 NASA purchased a Convair 990 four-engine jet transport for research purposes. This aircraft had been used for flight testing and certification, and was altogether void of passenger accommodations (fig. 1). This made possible, within limits, the optimization of the design and location, of various systems. The modified interior is shown in figure 2. Most significant for the 1965 solar eclipse expedition was the cutting of 13 view ports on the airplane's left, at 65° elevation (figs. 3 to 8).

A coordination meeting was held on 2 November 1964 at the Los Alamos Scientific Laboratories (LASL) for scientists interested in airborne experiments for the 30 May 1965 solar eclipse. The purpose of this meeting was to assign space on three available aircraft: NASA's Convair 990 and two KC-135's operated by the U.S. Air Force for LASL and Sandia Corporation. Another KC-135, operated by the Air Force Cambridge Research Laboratories (AFCRL), was not considered for airborne experiments, as AFCRL could not accommodate guest scientists. Most of the experimenters considered had made their interest known to the Douglas Aircraft Company (DAC), who had previously solicited such expressions of interest, and who very graciously placed their list at our disposal; others had been in touch directly with LASL and Sandia. There was not time for additional announcements or solicitations of proposals. As it was, there were more proposals than space available, and each aircraft was assigned a greater load than it could carry. This overload was resolved through withdrawals of experimenters who could not meet the established deadlines or other requirements. The NASA list of experimenters and experiments, which became final on 1 April 1965, is given in table I. The assigned locations on the airplane (fig. 4) became final on 4 May.

An experimenter's meeting was held in Santa Monica and San Diego, California, on ll-12 February 1965. The first day was devoted to descriptions of various expeditions, including the airborne NASA, LASL, Sandia, and AFCRL, and ground based expeditions planned for the islands of Manuae and Bellingshausen (coordinated by Kitt Peak National Observatory). The morning of the 12th was split into two sessions, and the afternoon was devoted to visiting the airplane undergoing modifications at the Convair plant in San Diego. One of the morning sessions was spent in detailed hardware discussions with the experimenters assigned to the NASA aircraft (mounting and other interface problems). Pictures showing the experimenters' equipment in the airplane are given in figure 9.

The second session was an operational logistics and coordination meeting for the airborne expeditions (NASA, LASL, Sandia, AFCRL). The path of totality of the 30 May 1965 solar eclipse started in New Zealand at sunrise, curved north-east to just above the Equator, then proceeded down to the coast of Peru at sunset[1] (fig. 10). The point of maximum duration on the ground ($5^m\ 20^s.4$) was at latitude -2° 05'.7, longitude +l32° 57'.7 (ref. 3). Since the sun line was at a right angle to the path at this point, this general area was the most favorable from a scientific standpoint. Coordination of ground support and flight paths for the four aircraft proceeded on the assumptions that tracking ship support would be available and that the expeditions would be based in Papeete, Tahiti, where the jet landing field nearest eclipse intercept was located.

The anticipated support of the USNS Range Tracker was withdrawn because of higher priority commitments in support of the Gemini-Titan 4 manned space flight, but NASA was able to secure support from the USNS Wheeling by mid-April.

More serious was the fact that Tahiti was not made available as a base of operations. Another coordination meeting was held in Washington, D.C., on 27 February 1965, to establish revised flight operation plans. Several alternates were agreed upon, but it was another month before firm plans were established. The NASA aircraft had just enough range to operate from Hilo, to Hawaii, by intercepting slightly west of the scientifically optimum point, with some loss in observing time and a less favorable viewing angle; or, alternately, it could go to the optimum if Tahiti could be used for a brief refueling stop was after the eclipse. The AFCRL aircraft had enough range to meet all objectives operating from Hickam Air Force Base (Honolulu), the only drawback being an excessively long flight. Tracking ship locations were agreed upon, satisfying the requirements of AFCRL and both of NASA's possible intercept points. The LASL and Sandia aircraft did not have enough range to operate from Hawaii, and would base in Pago pago, Samoa. They would intercept just east of the Island of Bellingshausen (which would be used as a navigational fix), at a loss of about 45 percent in observing time and a much less favorable viewing angle.

The NASA aircraft did intercept at the optimum point and refuel in Tahiti on 30 May (figs. 10 to 12). Two disadvantages were the excessively long flight times, and the fact that practice flights had to be executed to simulated intercept points within range of Hilo. This last item meant different relationships to the tracking ship and different weather conditions for the practice flights and for the eclipse flight; some of the difficulties discussed in the Navigation section of this report are traceable to these different conditions. In retrospect, however, it was felt that the Hilo base made ground support arrangements and communications with the U.S. Mainland considerably easier, and this far outweighed the above mentioned disadvantages. Local ground support arrangements were made in Hilo during the week of 6-11 April (table II).

Aircraft modifications were completed the first week in April, and the

---

[1]An amusing aspect which seems to have escaped attention is that this eclipse ended the day before it started, by virtue of the fact that its path crossed the International Date Line. The same situation attracted considerable comment in 1948.

airplane was transferred from San Diego to Moffett Field on 2 April. A timetable allowing some flexibility was set up for the period of 15 April to 8 June 1965. The actual schedule and the flight descriptions, as given on tables III and IV and figures 11 and 12, deviated only slightly from the original plan. It took longer than anticipated to install and check out subsidiary systems, and some flights had to be rescheduled because of operational problems. In retrospect, all flights were needed, as were all days between flights. Flight participants are listed in table V.

The following sections describe the principal aircraft modifications and installations (view ports, power supplies, and digital time clock) and the navigation and aircraft performance (stabilization, guidance). Appendix A gives details of the eclipse intercept events, primarily for the benefit of the experimenters.

OBSERVATION PORTS

Thirteen ports with 12 X 14-inch clear apertures were cut into the fuselage on the airplane's left, at an elevation of 650 (to match the elevation of the sun at eclipse intercept). The size and location of these ports (figs. 3 to 8) were determined in large part by structural considerations. Seven experimenters provided their own optical glass (quartz,fused silica, arsenic trisulfide, calcium fluoride, borosilicate crown no. 2). One experimenter (Station 6) used the regular plastic passenger window without the inner pane (fig. 13). The remaining observational windows were provided by Ames. These are reground and repolished soda-lime plate glass, specially selected for minimum bubbles and striae, and surfaced on both sides. Each pane is flat to a maximum of 4 fringes per inch and its surfaces are parallel to 0.001 inch. All panes have magnesium fluoride antireflection coatings.

The optical glass was held in aluminum frames with silicon-rubber gaskets (fig. 7). Special frames were made for optical glass of nonstandard size. The aluminum parts of the assembly were sandblasted and anodized black to curtail extraneous reflections. It was noted after the expedition that much of the black anodizing had been removed from the outside surface. Solar radiation and/or the boundary layer may have been responsible.

Each window assembly is installed from the cabin and presses against a gasket on the restraining edge of the fuselage skin. Two aluminum shoulders, 3 inches long, are then cinched up against the inside of the frame. On the ground, it is practically impossible to press the window tightly enough against the gasket to make an effective seal. A positive, leak proof seal is, however, produced by the pressure differential across the window at high altitude. Each window is inspected after reaching altitude and the restraining shoulders are tightened against the frame (a gap of 1/8 inch was usual). Once a window assembly has been pressurized and tightened in flight, it retains its positive seal until it is removed again from the aperture.

Each window assembly was safety-tested in a vacuum chamber, as follows: First, it was subjected to a pressure differential of 140 cm of Hg at room temperature for 5 minutes to check its pressure seal. Then a pressure differential of 99 cm of Hg and a temperature differential of 110° C were maintained simultaneously across each window for 20 minutes. The assembly was then returned to ambient room conditions in 2 minutes. All the window assemblies passed these tests. On the eclipse flight, the differentials were approximately 41 cm of Hg and 80° C.

The glass procurement, frame manufacture, and safety testing were performed under contract by the Douglas Aircraft Company. Further details may be found in reference 4.

Plastic safety windows are mounted on the inside of the observation windows (fig. 6). Sliding in horizontal tracks, they are moved out of the line of sight during the observation period. In the closed position, the safety windows press tightly against a gasket seal. In case of failure of an optical window, the cabin pressurization can be maintained against remaining leakage. The safety windows were opened by the individual experimenters approximately 10 minutes before second contact, and closed soon after third contact. No optical glass failures occurred.

Because of the very low outside temperatures (about -50° C) at operating altitudes, cabin moisture tends to condense on the inside of single pane windows. A defrosting system (fig. 8) was installed to keep the optical glass free of condensation. Warm air (about 40° C) is bled from the cabin air conditioner to a series of 15 small openings across the top of each optical port. A manual butterfly valve is installed in the duct to each port to allow individual control of air flow. The temperature of the exit air (after passing over the window) at full flow is estimated to be 20° C, while the inner window surface, under extreme ambient conditions (fig. 14), is calculated to be at l6° C. When the plastic safety window is in the closed position, the exhaust air passes into the cabin through orifices in the lower window frame. No quantitative experimental data are available for comparison with the estimates of figure l4, but it was found that full flow was not necessary to keep the windows clear of condensation.

A significant amount of oil vapor is present in the air conditioning system when it is first turned on. The inside surfaces of the optical windows were protected by sheets of plastic or paper taped around the edges. The protective sheets were removed for periods of l to 2 hours, including the astronomical observing time, during which no significant amount of oil was deposited. Most experimenters adjusted their butterfly valves to the minimum flow that would keep the windows free of fog. Since this undoubtedly meant a lower glass temperature than at full flow, it may be that there is an intermediate optimum flow to minimize oil film formation.

Lightweight, jettisonable plastic covers were devised to keep the outside of the optical windows clean and dry on the ground. A cover was designed which gave satisfactory protection and which ejected successfully in 38 out of 39 cases. This cover, an inverted tray with four horizontal stiffening ribs on the outboard side (fig. l5), was held in place by a small bar on the leading edge and sealed to the fuselage with 3/4-inch electrical tape. The restraining bar is pushed outward in flight by means of a plunger, and the leading edge of the cover is lifted into the air stream and the cover ejected.

Because there remained some concern regarding the reliability of cover ejection, the experimenters elected to take off without covers and chance possible contamination during engine ground run and takeoff. To minimize the danger of contamination, the fuselage was washed and sheets of plastic were taped to the fuselage around each window and removed externally about an hour before takeoff. This was not entirely satisfactory, in that some contamination of the outside glass surfaces did occur, presumably due to engine exhaust during ground run and taxiing. This method was, furthermore, operationally extremely awkward, and did not provide an effective seal against a heavy rain.

An interesting phenomenon was the appearance of water droplets on the windows during the early stages of climb, even though the windows and fuselage surfaces had been carefully dried just before takeoff. It was hypothesized that this was due to an air-flow expansion effect at the leading edge of the window frame, giving rise to condensation of moisture from the boundary layer.

Two problems remain concerning the optical windows. Additional studies need to be made to design an exterior cover that will protect the window surface from atmospheric dirt and moisture and that can be more reliably ejected in flight. Second, a rainwater leak between the optical glass and the frame assembly (fig. 7) must be corrected.

EXPERIMENTERS' ELECTRICAL POWER

Aircraft Power

Schematic diagrams of the cabin power distribution system are shown in figure 16. The basic power source consists of a 40 kVA generator in each of the four jet engines, producing 200/115 V, 400 c/s, three-phase, four-wire, wye-connected power. Constant-speed drives hold the frequency within ±l percent; the line to neutral voltage is regulated within 2.5 V. The four aircraft generators are normally paralleled on a synchronizing bus, from which the 400 c/s power is carried directly to groups of four experimental stations and also to four 60 c/s converters. The generators can also be switched at the flight engineer's panel in the cockpit so as to operate independently of the synchronizing bus, as shown on figure 16(a). A master circuit breaker at the engineer's panel can shut off all experimenters' power.

The distribution of power to the 16 experimental stations is controlled at the coordinators' console (figs. 4,17). The power is brought out at dual junction boxes serving pairs of experimental stations (figs. 4, 18).

The experimenters' 400 c/s power goes directly to the junction boxes from the generators (fig. 16(a)). The coordinators do, however, have on-off switches and power indicator lights (fig. 17) for each set of four stations. The junction boxes contain three-pole, 30 A circuit-breaker switches by which the individual experimenters control their 400 c/s power (fig. 18). The flight engineer monitors the 400 c/s voltage on the synchronizing bus through meters on the flight deck. There is no current monitoring for the 400 c/s power.

Four solid-state frequency converters (Unitron PS-62-66-01) were installed in the forward cargo compartment, which is pressurized and easily accessible in flight (hatch C, fig. 4). Each converter has a rated output of 3.5 kVA, 115 V ±1 percent, single phase, 60 c/s ±0.01 percent.

The coordinators' console has complete and flexible control over the 60 c/s power distribution (figs. 16(b), 17; note that the flight engineer can shut all experimenters' power off in an emergency). A patch cord arrangement permits each experimental station to be connected to any of the four converters. The circuit breaker switches at the coordinators' panel were rated in accordance with expected loads at each station. (On-off SPST switches are the also provided at the junction boxes.) Four ammeters permit monitoring the individual converter loads. The 60 c/s load distribution during the eclipse flight is shown in table VI.

Some trouble was experienced with the converters. The problems seem to be related to load transients and attempts to correct these difficulties are in progress.

Requirements for dc power were met by small individual supplies that operate directly from the aircraft's 400 c/s system (I.T.T. No. FTR-p-46lA). The unregulated outputs range, typically, from 28 V at no load to 24 V at full load of 20 A.

Electrical Interference Tests

Investigations of possible electrical interference between the various aircraft and experimental equipment were repeatedly carried out. With two exceptions, as noted below, no such interference was positively identified. These lengthy and tiresome tests were, however, deemed extremely valuable in that many potential sources of trouble were uncovered and corrected.

The aircraft's Freon cooling unit for the air-conditioning system did definitely produce a large starting current surge with long decay pulses that affected experimenters' equipment. A line voltage drop of 10 to 15 V for about 20 ms typically occurred. The Freon system can be turned off at high altitude, since the cold outside ram air used in the heat exchanger is sufficient to handle most of the air conditioner load. The Freon system was therefore turned off during the experimentally critical parts of the eclipse flight.

The second source of interference that was identified was the aircraft's uhf transmitter, which, when in use, introduced spurious signals on the Station 3 equipment. This transmitter was, therefore, not used during eclipse intercept.

Ground Power

On the ground at Moffett Field, the aircraft's electrical system was energized by a 125 kVA, 400 c/s, three-phase, ground power cart. At Hilo, such a ground unit was available only infrequently. Power (60 c/s) for the refrigerators and a few experiments was made available at all times by means of a long extension cord from the fire station hangar to the coordinator's console on the airplane. This was not satisfactory since large voltage drops were very noticeable and extreme care is required to insure that the polarity of the external 60 c/s line matches that of the aircraft's system. Because of the importance for the experimenters to have 400 c/s available on the ground for systems checks, a stronger effort will be made in the future to secure a 400 c/s power cart at the operating bases.

TIMING PULSES

Time Code Generator

Time information for the eclipse flight was furnished by a time code generator (TCG), Chrono-log Corp. model 20,001, synchronized to radio stations WWV and WWVH. The instrument provides both a visual display of the time of day on its front panel and a variety of time codes and pulses to the experimental stations. An internal 1 Mc crystal oscillator mounted in an oven is used as the frequency standard; the oscillator has an inherent stability of one part in 10^8 per day.

The time code generator is located on top of the tool cabinet just aft of the coordinator's console (figs. 4, 19). Output leads were run directly across the ceiling to the gutter strip (along the left-hand wall) that contains the power wiring to the experimental stations (fig. 18). The time signal leads are brought out in a BNC connector beside the electrical power junction box at each experimental station (fig. 18).

Synchronization to Universal Time

The time code generator clock is synchronized with time signals broadcast by WWV and WWVH. By using an oscilloscope, one can synchronize the clock's output with the WWV signals to within 0.01 second. The experimenters' requirements were not that stringent, and it was sufficient to set the clock just by listening to the WWV time signals; with practice, an accuracy of 0.1 to 0.2 second can be achieved in this manner.

The aircraft's high frequency (hf) radio can be monitored at the coordinators' station, but WWV reception is interrupted by the flight crew's air to ground communications, which require changes in the receiver's frequency settings. Therefore, a special WWV receiver was mounted above the time code generator. A separate antenna could not be installed in the time available, but the aircraft's electronics crewman was able to match the aircraft's hf antenna to the receiver. A strong radio signal was then readily available, except when the flight crew was actually transmitting on hf. Time marks were also occasionally requested from the tracking ship.

On the West Coast, the WWV signal from Washington is usually stronger than the WWVH signal from Honolulu. At Hilo, Hawaii, and on the flights out of Hilo, WWVH was, of course, loud and clear. Near Tahiti, however, WWV came in much stronger than did WWVH at 10 Mc/s.

Output Time Signals

The time code generator provides two general types of outputs, the absolute time of day in binary coded decimal form (BCD), and timing pulses or markers. The BCD code is the NASA 36-bit format (ref. 5), in which a 1 kc/s carrier wave is amplitude modulated to read out, over an interval of l second, the time of day in hours, minutes, and seconds. Three experimenters (Stations 6, 7, 10; fig. 4) put a variation of this serial code, the "level shift," onto paper chart recorders. Depending upon the speed of the paper feeds, the time code is more or less easily decipherable. For example, a chart speed of 1 inch per second gives a trace that can be read to 0.0l second with a low power magnifier.

The BCD code is also provided in parallel channels for instantaneous readout, one channel for each bit in the time code. One experimenter (Station 3, fig. 4) used part of this output to record the absolute time in minutes and seconds on 12 channels of a magnetic tape.

Another general type of output from the time code generator consists of accurately spaced pulses at various intervals. Several experimenters used the seconds and the minute pulses to put timing markers on their charts and tapes and also to operate relays.

Performance of the Time Code Generator

The time code generator did not operate as reliably as had been expected. On the early practice flights, the main error was a sudden skipping or jumping ahead in time. It was found that a signal randomly triggering the "tens of seconds" decade was coming from the experimental load that used the parallel BCD output. Blocking diodes stopped this source of trouble. No source of interference from the 60 c/s input power lines was positively identified; however, it was felt advisable to insert 0.02 microfarad capacitors between each side of the input line and chassis ground. The clock rapidly lost time, of the order of a few seconds in ten minutes, when it was connected to the aircraft power system. It was therefore decided to operate the time code generator entirely from independent dc supplies. The source of the TCG malfunction was later found to be a defective transistor in the voltage regulation circuit.

The clock had to be periodically reset to WWVH signals, as shown on table VII, which gives the TCG performance on the eclipse flight. The last resetting had to be made at 21: 05: 00 UT, about 15 minutes before second contact. Further checks against WWVH indicated that it remained accurate within 1 second throughout the period of totality. These checks were made at 21:26:00, just past the midpoint of totality, and again at 21:34:00, about 3 minutes after third contact.

Four discontinuities in the time code outputs during totality are, however, evident in the records taken at different experimental stations. They can be seen, for example, in the BCD serial "level shift" output as recorded at Station 7 by a "Visicorder" chart running at 1 inch per second (table VII and fig. 20). The records of the seconds pulse, used by many experimenters, show the seconds interval to be of non-uniform length at these four times. These records cannot be used to determine the timing error since they do not indicate whether a second marker was omitted or repeated.

NAVIGATION

Navigation Strategy

The navigation scheme for the eclipse flight consisted of three distinct phases: (1) enroute navigation to and from the tracking ship's radar horizon; (2) time-loss maneuver and initial line-up for the eclipse run; and (3) the constant sun-bearing flight path during totality. The use of a tracking ship, the USNS Wheeling from the Pacific Missile Range, was necessary because of the precise navigation required, the absence of landmarks and other navigational aids (such as LORAN) in the area of interest, and the lack of time necessary to install sophisticated inertial navigation equipment during the tight schedule prior to the expedition.

The time of departure from Hilo was set so as to reach the ship early, and then adjust the path around the ship (fig. 11) to meet the intercept point at the correct time. The enroute navigation was accomplished with a standard artificial horizon periscope sextant. The maximum distance off course at initial radar acquisition by the ship was 5 miles, and all initial acquisitions were made at a range of more than 200 miles (less than 10 above radar horizon).

Having been acquired by the ship, the aircraft would then receive every 3 minutes position reports consisting of latitude, longitude, time, and ground speed. These position reports were transmitted to the aircraft within 30 seconds of the actual time of the fix. The navigators would then use this information to calculate the appropriate time-loss maneuver and to line up the aircraft on the preplanned intercept path. The time-loss maneuver consisted of turning westward to intercept an extension of the "hot run" path at a point consistent with the amount of time to be lost (fig. 11). A racetrack pattern, which is the standard method for achieving a controlled time of arrival, was not used in this case for the following two reasons: 1) the number of turns had to be minimized because the ship's radar had difficulty maintaining lock-on while the aircraft was in a bank; and (2) to obtain maximum stability from the autopilot gyro, turns had to be limited to shallow bank angles, and a straight run for at least 10 minutes prior to intercept was desired to damp out gyro precessions due to the last turn.

Once on the intercept path and within 5 minutes of second contact, the constant sun-bearing maneuver would be made with a remote autopilot control from information presented on the sun compass (the sun compass and remote autopilot control are described in the Airplane Stabilization and Guidance section of this report). During this phase, the ship's position reports would only be monitored and used for post-eclipse data rather than for heading changes during totality.

Navigation and Communications Equipment

USNS Wheeling - The navigation, communication, and tracking equipment aboard the USNS Wheeling is indicated below:

Tracking instrumentation:	AN/FPS-16 radar (C-band) - with plotting board and digital tape readout.
Acquisition aid:	Agave (215-260 Mc/s)
Navigation:	SINS (Stellar Inertial Navigation System), updated by star tracking and navigation satellite.
Communication:	hf, uhf, vhf radios.

The FPS-l6 radar is the most accurate of shipboard radars. Position accuracies, assuming favorable geometry, should be within ±100 feet relative to the ship. The SINS, with updating, provides a ship positioning accuracy of ±0.5 nautical mile.

Convair 990 - The aircraft navigation and communication equipment consisted of the following:

Navigation:	Periscopic sextant with illuminated horizon line, a specially designed sun compass improvised by the Douglas Aircraft Co., weather radar, C-9 compass system, dual VOR (vhf Omni Range) receivers, ADF (Automatic Direction Finder) receiver, and a C-band beacon transponder.
Communication:	hf, uhf, vhf radios.

Practice Flights From Moffett Field

After several conferences with USNS Wheeling personnel to establish operating and coordination procedures, several flight tests were deemed necessary to 1nsure that all cr1t1cal equ1pment was operat1ng and that constant radar tracking and radio communication could indeed be maintained for extended periods of time.

Three practice missions were flown near the Wheeling (table IV) and, as expected, several difficulties were encountered with equipment on both the ship and the aircraft. In particular, the aircraft crew had difficulty keeping the uhf keyed. Because the malfunctioning uhf radio was the primary means of positioning the ship's radar antenna, radar acquisition could only be maintained for very brief periods during the first and second flights. Prior to the third flight, the uhf problem was solved and the aircraft was acquired and held during a simulated eclipse run.

Practice Flights From Hilo

Three practice flights were scheduled from Hilo (table IV) to a pre-selected point south of the equator where the Wheeling was stationed (fig. 11). The actual eclipse area could not be used for this practice because the range limitations of the aircraft would not permit a flight to this area and return to Hilo. The staging area chosen duplicated the "hot run" area as closely as possible in that it was the same distance south of the equator. On the first Hilo practice flight, the ship's computer malfunctioned but radar acquisition was made at maximum range and constant tracking was maintained. The last two practice flights were flawless. It was standard operating procedure to debrief on hf radio immediately after each simulated eclipse run to clear up any existing or possible future problem areas.

The practice missions, flown from both Moffett and Hilo, proved invaluable to the success of the project. They provided the experience necessary for the smooth coordination in the continuous flow of data between the aircraft and the ship, as well as between members of the crew. The Wheeling's tracking crew had never worked with an aircraft but, after only a short practice period, did an outstanding job during the final two "dry runs" and the actual eclipse flight.

Intercept Procedures

Detailed eclipse geographical and timing information charts were prepared under contract by the Douglas Aircraft Company (ref. 4). The enroute flight line chosen by the navigators was a direct line from Hilo to the Wheeling (fig. 11) in order to take maximum advantage of the ship's radius of radar coverage. The ship was positioned 160 nautical miles north-west (toward Hilo) of the eclipse intercept point (figs. 11, 12) because it was considered more important to have early acquisition and constant tracking capabilities during the critical time-loss maneuver and line-up than to have coverage during the entire length of totality.

Two important parameters were determined during the practice missions: (1) the maximum range from the ship that would insure continuous radar lock-on was found to be 160 nautical miles; and (2) the takeoff time had to provide for a 15 minute time interval for keeping the time-loss maneuver within the bounds of that 160 nautical mile coverage. These conditions were met by the takeoff at 16:57 UT (06:57 Hawaiian time). The pilots made immediate voice contact with the tracking ship on hf and advised them of our takeoff time. The navigators requested that the ship's weather station measure the winds at 38,000 feet with a balloon one hour before the aircraft was to reach the ship's radar range. The wind information obtained from the ship indicated that there would be 30 of right drift and a 15-knot tail-wind component on the eclipse run. The navigators corrected the eclipse maneuver for the anticipated right drift and ground speed increase just prior to initial radar contact.

Acquisition was made and the first position report was received at a range of 217 nautical miles from the ship. The first fix indicated that a strong, unpredicted tail wind had decreased the enroute time by 8 minutes and therefore increased the required time-loss maneuver from the planned 15 minutes to 23 minutes. The maneuver planned for maximum loss of time was initiated at the predetermined point and the aircraft flown to the far edge of the safe 160 nautical mile boundary for positive radar lock-on. Only 22 of the required 23 minutes were lost, but the sacrifice of one minute was considered less important than the chance of losing radar acquisition at this critical time. During the line-up phase, it became obvious that the wind was stronger than the ship's weather balloon had measured and that we would be from 1-1/2 to 2 minutes earlier than planned. With the help of the time and position error matrix tables (ref. 4 and table VIII), the navigators predicted the time of second contact and the duration of totality and informed the coordinator's station so that the countdown could be corrected (further details are given in appendix A).

At a point 5 minutes from predicted second contact, the autopilot control was assumed by the remote station, which was located opposite the sun compass. The sun was kept 90° abeam the aircraft during the entire duration of totality by keeping the aircraft in a very slight left turn. The amount of turn needed was determined by watching the sun's image on the sun compass.

Results

The intercept maneuver, corrected for left-to-right cross wind, called for cutting across the center of the umbra path from north to south, with second contact north, mid-totality exactly on, and third contact south of the center path. Because the aircraft was 2 minutes ahead of the scheduled time and the cross-wind component stronger than predicted, the aircraft crossed the umbra center path at second contact (fig. 12). The southward drift was underestimated by about 5 nautical miles during the flight, so that the estimated totality duration was about 10 seconds too long (see table VIII). Part of the reason for the discrepancy in wind data was that the aircraft was flying at a pressure altitude of 38,000 ft, which was a geometric altitude of 39,500 ft. The ship's predictions had been made for a geometric altitude of 38,000 ft.

A replot of the Wheeling's computer information after the expedition showed that the aircraft was l3 nautical miles south of the umbra center at mid-totality. The loss in totality was more than compensated for by the increased duration caused by the tail wind which increased the ground speed to 5l0 knots from the planned 490 knots. The length of totality was measured at 582 seconds. The aircraft positions at second and third contact were 0l° 48' S l32° 04' W, and 0l° 3l' S l30° 44' W, respectively (table IX). Appendix A gives a detailed account of the events during intercept.

AIRPLANE STABILIZATION AND GUIDANCE

The ability to maintain close tolerance airplane stabilization and precise heading control was essential to the success of the eclipse mission. Many of the astronomical instruments were limited in sluing range and field of view. Some of the instruments were hand guided and, thus, relied upon airplane stability to facilitate tracking of the eclipsed sun. In addition, a gradual (l/3°) and coordinated left-bank turn was required of the airplane in order to maintain a constant sun-bearing angle for the observers during totality. The theoretical turn radius was 592 nautical miles, and the total heading change was l2.8° during the 16 minutes from 5 minutes before second contact to 2 minutes after third contact. Since these restrictions and requirements were beyond the limits of human pilot capability, attention was focused on using the airplane's autopilot to achieve the desired control.

A standard SP-30 autopilot controls the automatic heading and attitude of Convair 990 airplanes. For commercial operations, the autopilot is set to operate over the entire flight envelope, that is, for various altitudes, airplane speeds, and load conditions. In this mode, the autopilot can control airplane oscillations to within approximately ±2°. For the eclipse flight, an attempt was made to enhance the autopilot's stabilizing capability to ±l/4° by tuning it for the anticipated flight environment (a 38,000 ft altitude and a true airspeed of 490 knots, with a gross weight of l80,000 lb).

Because of lack of time a relatively simple technique was used to achieve the required gradual left turn. A precession control subsystem was added to the gyrocompass which provides airplane heading data to the autopilot. It was "Tee" connected between the compass gyroscope and the gyro aircraft harness. By means of a switch on the control, the gyroscope could be de-slaved from the earth's magnetic field and allowed to operate as a free directional gyro. A synthetic precession voltage from the control box could then be applied to the torque motor of the gyrocompass to send a heading error signal to the autopilot, thus causing the airplane to turn. It was possible to pre-select any desired airplane turn rate by varying this precession voltage with a potentiometer. In addition, a high and low precession voltage range switch was series-connected to the potentiometer. The high-low precession voltage was selected in conjunction with the potentiometer setting to maintain a smooth, coordinated left turn.

To calibrate and tune the autopilot, a variable-gain calibrator was attached to the autopilot's flight control computer. Seven adjustments of the calibrator were possible: (1) yaw lagged acceleration gain, (2) roll lagged acceleration gain, (3) roll displacement gain, (4) rudder synchro excitation, (5) aileron servo excitation, (6) rudder servo tachometer excitation, and (7) aileron servo tachometer excitation. The only adjustments which had any advantageous effects on airplane stability were found to be yaw and roll lagged acceleration gains. By increasing both of these to the extent that both yaw and roll control of the CV-990 were highly over-damped, short term stability could be maintained to within ±0.25° in yaw and roll (fig. 21).

A sun compass was installed aboard the aircraft to monitor the azimuth (or bearing angle) and elevation of the sun during the various practice flights and the actual eclipse run. The device consisted of a long focal length lens and a mirror mounted at the forward-most passenger window on the left side of the cabin, and a 3-foot grid card mounted on the navigators' desk across the aisle (fig. 22). The lens was oriented so that the incoming beam from the sun was normal to the lens with the airplane at 1.8° pitch angle and 1/3° left bank (left wing down by 1/3°), and the sun near 65° elevation. Light from the sun passed through the lens and was reflected by a mirror to in the grid card across the aisle.

Using a sun compass for aerial navigation dates back at least to the 1929 south polar flight by Admiral Byrd. The sun compass used during the 1965 eclipse was actually an outgrowth of a similar instrument used by the Douglas Aircraft Company and National Geographic Society Eclipse Expedition of 1963 (ref. 2). A significant difference was that the airplane was not required to bank during the 142 seconds of totality observed in 1963. Thus, whereas the sun compass served as a navigator and flight progress monitor on the 1963 flight, it was used as a guidance indicator on the 1965 expedition. The procedure was as follows.

After the airplane had made the final turn onto the eclipse track, and was aligned for intercept (fig. 12), the solar image appeared on the compass and grid. Since the alignment turn was completed about 5 minutes prior to second contact (to facilitate gyro stabilization and erection), the image appeared a few degrees to the right of the 90° sun-bearing line (fig. 22). As the image slipped into the proper position on the grid card, control of the autopilot was switched from the magnetic compass to the slow turn-rate controller. With the potentiometer set to provide the synthetic precession voltage required for a 1/3° bank angle, the bank switch was then placed in the "bank left" position. As the left wing dropped, the image could be seen to move slightly upward on the grid card. Small attitude oscillations were readily observable on the grid. The median position of the image was used to determine when changes in the potentiometer setting should be made. Since the changes were small, there was an appreciable lag between input and observed response.

The practice flights were quite helpful in developing these control techniques. During the darkness of the actual eclipse run, the faint image of the corona could be seen on the sun compass grid but the bearing and elevation lines could not. A flashlight was hastily masked to provide a source of low intensity light to illuminate the grid card intermittently.

To monitor the motions of the airplane, wide angle, rate-integrating gyroscopes were rigidly attached to the airplane's structure and approximately aligned to each of the principal airplane axes. The output of the gyros (recorded on a strip-chart oscillograph) thus indicated the angular deviations of the aircraft from a set of inertial reference axes established by the gyros. From these records (fig. 21), the aircraft roll, yaw, and pitch motions could be studied. The periods and maximum amplitude excursions for the airplane during the actual eclipse flight were approximately as follows:

Period, sec	Roll, arcmin	Pitch, arcmin	Yaw, arcmin
0.2	±6	±2.4	±1.2
5	±12	±3	±6
100	±42	±6	±24

The eclipsed sun was photographed at 24 frames per second with a fixed 16 mm motion picture camera. By measuring the excursions of the solar image on the film we deduced the combined roll-pitch and yaw-pitch airplane oscillations. These data agree, as one could expect, with the gyroscope records.

Figure 23 shows a portion of a record of bearing angle during totality. The oscillations in bearing showed generally the same approximate frequencies as did the basic aircraft motions, and the bearing excursions were generally within ±1/2°.

Ames Research Center
National Aeronautics and Space Administration
Moffett Field, Calif., Jan. 10, 1966

APPENDIX A

COUNTDOWN

A countdown was given by the coordinators over the public address system, and was partly recorded by some of the experimenters. The events during the eclipse flight countdown are summarized briefly here and will serve as an illustration of procedures and as a clarification and record for the expedition participants.

The following countdown was given during the practice flights, and was also intended for the eclipse flight:

Speaker	Time	Announcement or action	Remarks
Bader	B - 1 hr	"It is now one hour before second contact. Time to cover the passenger windows."	B stands for Beginning of totality, or second contact.
Haughney	B - 45 min	A time marker was given to permit experimenters to set their watches.	This marker was given at a convenient round number time, not at exactly B - 45.
Bader	B - 30 min	"It is now a half hour before second contact. Everyone should be at his station within 10 minutes for aircraft stabilization."	
	B - 25 min	Time marker.	
	B - 20 min	"Everyone should now be at his station. Please keep personnel displacements to a minimum. The aircraft is being stabilized."	
Bader	B - 20 min	Use dimming of cabin lights as time marker.	This marker was exactly 20 minutes prior to estimated second contact.
	B - 10 min	Various reminders: Time, open safety windows, remove lens caps, etc.	

Speaker	Time	Announcement or action	Remarks
Bader	B - 10 min	Turn off cabin lights, use as time marker.	This marker was exactly 10 minutes prior to estimated second contact.
Haughney	B - 5 min to B + 300 sec	"5 minutes to go; 4, 3, 2, 1; 30 seconds, 20, 10, 9, 8, . . ., 2, 1, 0; 10 seconds after second contact; 20, 30, . . ., 300."	This was according to navigators' estimates as of B - 5 min, and did not exactly match second contact. During this time, Bader was getting updated information from the navigators and from observers at Station 1.
Bader	E - 240 sec to E + 2 min	"4 minutes before third contact; 230 seconds; 220, 210, . . ., 0; 10 seconds after third contact; 20, 30, . . ., 120, we are now turning back." Signal given to pilots to start return trip.	E stands for End of totality, or third contact. This was an updated, recalculated countdown, intended to match third contact exactly.
	E + 10 min	Reminder to close safety windows and tie down equipment.	The aircraft remained dark and on autopilot for a longer time, for the benefit of experimenters making calibrations.

The countdown never went precisely according to plan, primarily because of a heavy load of interphone calls between the coordinators' console and the experimenters. These calls took priority over other coordinator activities, as the possibility was always present that an incoming call was an emergency.

At B - 1 hr, during the eclipse flight, the passenger windows were covered. Enough light was coming through the optical ports so that the cabin was not significantly darkened. At approximately B - 45 min, it was requested by Station 10 that cabin lights be turned off, and the cabin got progressively darker thereafter. This request made an announcement necessary, so that "lights off" would not be interpreted as the B - 10 min marker. Thee B - 45 min marker was given at about B - 46 min, and the B - 20 min marker was modified as the lights were already off. The B - 10 min marker was not given, as there was a heavy communication load between Bader and the navigators, and Haughney was busy with the TCG, the power converters, and experimenters calls. The estimated time of second contact was revised by the navigators at about B - 12 min, thus adding to the confusion.

The countdown from B - 5 min to B - 2 min was not heard over the public address system because a switch had been left in the cabin interphone position. At that time, Haughney received a request for timing information from Station 11, and, almost simultaneously, Bader found out from Reynolds that the aircraft was about 2 minutes ahead of schedule; the revised estimated B was 21:20:10. This was announced, and the countdown was resumed at B - 4 min. No further experimenters' calls were received.

Bader switched to monitoring the Station 1 interphone. Kissell called out "corona" just about when Haughney got to "zero." Bailey's beads were noted by Kissell, and could also be seen by Bader by glancing over to the sun compass chart over the navigator's console. "Contact" was noted by Kissell 29 seconds after "zero." The actual second contact UT, 21:20:40, was given by Bader to Reynolds, who then computed totality duration with the help of the updated position and velocity information and an error matrix chart (see section on Navigation). The tail-wind estimate was correct, but the cross wind had caused a larger drift than was known to the navigators at that time, so that the estimated duration was about 10 seconds too long. Bader recomputed the time of third contact, and took over the countdown. By glancing over to the sun compass chart, Bader noticed Bailey's beads and called "contact" right after "10 seconds to go." This was at 21:30:22.

The aircraft positions and times at second and third contacts are summarized in table IX. Because of normal scatter for visual estimates of times of contact, the various times and intervals quoted herein cannot be expected to be self-consistent to better-than ±2 seconds.

REFERENCES

l. Kinney, William A.: Operation Eclipse: 1948. The National Geographic Magazine, vol. 95, no. 3, March 1949, pp. 325-372.

2. Klemperer, W. B.: Project APEQS - Solar Eclipse Flight Expedition. Rep. G-36439, Douglas Aircraft Co., Sept. 1963.

3. Duncombe, J. S.; and Morrison, B. L.: Total Solar Eclipse of 30 May 1965. U.S. Naval Observatory Circular No. l02, Sept. l, 1964.

4. Cameron, R. M.: Douglas Tasks for Airborne Solar Eclipse Expedition of May 30, 1965. Rep. SM-48792, Douglas Aircraft Co., Aug. 1965.

5. Anon.: The Standard Frequency and Time Services of the National Bureau of Standards. U.S. National Bureau of Standards, 1965.

TABLE I. - LIST OF EXPERIMENTERS

Station	Names	Sponsoring organizations	Experiment
1	K. E. Kissell P. L. Byard J. D. Clarke	U.S. Air Force –Aerospace Research Laboratories	Inner corona infrared spectrum
2	L. Larmore A. Ireland	Douglas Aircraft Company	Chromospheric infrared spectrum
3	R. Stockhausen J. Mangus	NASA -Goddard Space Flight Center	Coronal infrared spectrum
4	M. Waldmeier	Swiss Federal Observatory, Zurich	Polar ray morphology
5	R. B. Dunn T. Cothern	U.S. Air Force – Sacramento Peak Observatory	Streamer spectrometry
6	R. E. Miller	Johns Hopkins University	Airglow
7	S. M. Smith R. A. Torrey M. E. Henderson	NASA -Ames Research Center	Streamer morphology and polarization
8	T. de Groot	Sonnenborgh Observatory, Utrecht	Limb darkening
9	G. Righini	Arcetri Observatory	Search for cold coronal regions
10 -11	A. J. Deutsch R. M. Cameron J. L. Whittaker J. J. Boyle	Mount Wilson - Palomar Observatories and Douglas Aircraft Company	Coronal spectra, visible region
12	F. V. Dossin P. Macar	University of Liege	Search for comets
13	W. N. Arnquist J. Waddell	Douglas Aircraft Company	Polarization studies
14	H. T. Mantis M. S. Carpenter	University of Minnesota and NASA -Manned Spacecraft Center	Polarization studies

TABLE II.- CHECK LIST FOR GROUND SUPPORT ARRANEMENTS

Flight operations	Experiments	Miscellaneous
Parking area and weight bearing capacity	Darkrooms	Contact city, county, airport, and other officials
Fuel: type, quantity, refueling schedules	Photographic supplies	Lodging
Waste disposal	Electronic supplies	Ground transportation
Starting units, prime and spare	Machine shops	Parking at airport
Electrical power	Dry ice	Conference room
Oxygen service	Distilled water	Access to ramp and aircraft at all hours
Weather information	Equipment storage	Passengers' access ladder to aircraft at all hours
Radio communications	Electrical power	Security
Systems repairs support: engine, hydraulic, electrical, electronic, mechanical	Air conditioning	Flight lunches
Landing fees and arrangements for paying	Tall ladders for optical ports servicing	Restaurant service to meet mission schedule requirements
Agricultural inspection and fumigation requirements	Toweling for washing fuselage above and forward of view ports	Passports, inoculations
		State Dept. arrangements
		Telephone service

TABLE III.- SCHEDULE OF OPERATIONS, 15 APRIL – 8 JUNE 1965

	April			May					June
		18	25	2	9	16	23	30	6
Installation of emergency equipment and subsidiary systems	xx	xxxxx	xxxxxxx	xxxxxxx	xxxxxxx	xxxx			
Reception of experimenters' equipment; uncrate, weigh, store		xxxxxxx	xx						
Installation of experimenters' equipment aboard aircraft		xxxx	xxxxxxx	x					
Briefing on operations and safety Procedures, and general meeting				5 May x					
Practice flights, Moffett Field				x	xx x x				
Aircraft maintenance						xxxx			
Flight to Hilo, Hawaii						22 May x			
Practice flights, Hilo, Hawaii							xx x		
Eclipse flight							30 May x		
Calibration flight								x	
Return flight to Moffett Field								3 June x	
Unload aircraft								xx	xx

TABLE IV.- FLIGHT DESCRIPTIONS

Flight number	Date (1965)	Takeoff time, UT	Landing time, UT	Distance, nautical miles	Purpose of flight
1	7 May	15:55	19:50	1700	Daytime practice
2	9	02:15	04:55	1160	Moon intercept
3	10	02:45	06:40	1700	Moon intercept
4	12	15:30	21:05	2420	Daytime practice
5	15	15:05	17:45	1160	Autopilot adjustments
6	15	20:00	23:10	1380	Daytime practice
7	18	16:45	18:00	540	System checks and ferry to San Francisco Airport
8	22	17:45	22:45	2160	San Francisco to Hilo
9	25	18:10	01:55	3376	Daytime practice
10	26	18:10	01:40	3355	Daytime practice
11	28	18:10	01:45	3365	Daytime practice
12a	30	16:53	01:15	3616	Eclipse flight; Hilo to Papeete
12b	30	03:50	08:35	2262	Papeete to Hilo
13	1 June	20:45	02:55	2242	Calibration flight
14	3	17:55	22:08	2021	Hilo to Moffett Field

Total flight hours: 73:40, exclusive of engine ground run time.

Total flight distance: 32,457 nautical miles.

Pacific Daylight Time: UT minus 7 hours.

Hawaii-Tahiti Standard Time: UT minus 10 hours.

TABLE V.- PASSENGER LISTS

NAME	FLIGHTS
Cockpit:	
W. B. Harwell, pilot (Convair)	1 2 3 4 5 6 7 8 9 10 11 12 13 14
L. E. Pilling, copilot (Convair)	1 2 3 4 5 6 7 8 9 10 11 12 13 14
L. Knudsen, flight engineer (Convair)	1 2 3 4 5 6 7 8 9 10 11 12 13 14
G. W. Stinnett, assistant manager for flight operations (NASA-Ames)	1 2 3 4 5 6 7 8 9 10 11 12 13 14
Navigators:	
P. R. J. Reynolds (Pan American Airways)	1 2 3 4 8 9 10 11 12 13 14
R. A. Acken (USAF and NASA-Ames)	1 2 3 4 5 6 8 9 10 11 12 13 14
Coordinators:	
M. Bader, expedition manager (NASA-Ames)	1 2 3 4 6 7 8 9 10 11 12 13 14
L. C. Haughney, assistant manager for experiments (NASA-Ames)	1 2 3 4 6 7 8 9 10 11 12 14
Aircraft systems support:	
L. Buczynski (Convair)	3 4 6
J. W. Cox (NASA-Ames)	8 14
W. M. Hill (NASA-Ames)	4 7 14
R. J. Moore (Convair)	1 2 3 4 5 6 7 9 10 11 12 13 14
L. E. Reich (Convair)	1 2 3 4 5 6 7 9 10 11 12 13 14
W. E. Romans (Sperry Gyroscope)	1 2 3 4 5 6 7 8 9 10 11 14
R. H. Tietjen (General Electric)	3 5 13
Experimenters and other passengers:	
M. Abzug	5 6
W. N. Arnquist	5 6 8 9 10 11 12 14
L. W. Boone	4
J. J. Boyle	1 2 3 4 8 9 10 11 12 13 14
C. Burdin	1
P. L. Byard	1 2 3 4 6 8 9 10 11 12 13 14
R. M. Cameron	2 3 4 6 8 9 10 11 12 13 14
M. S. Carpenter	1 12 13 14
J. D. Clarke	2 3 4 6 8 9 10 11 12 13 14
T. Cothern	1 2 3 4 8 9 10 11 12 13 14
T. de Groot	1 2 3 4 8 9 10 11 12 14
A. J. Deutsch	3 4 8 10 11 12 13
F. V. Dossin	1 2 3 6 8 9 10 11 12 14
R. B. Dunn	1 2 3 4 8 9 10 11 12 13 14
S. Edelson	6

TABLE V.- PASSENGER LISTS -Concluded

NAME	FLIGHTS													
<u>Experimenters and other passengers</u>:														
J. H. Enders								8						
B. A. Evans								8						14
J. D. Gehris	1			4	5	6				10	11			14
J. R. Gill	1													
J. J. Glatz	1													
R. Goodwin											11			
J. A. Hanly		2						8					13	14
G. Hardy							7							
J. T. Hatch				4		6								
M. E. Henderson	1	2	3	4					9	10	11	12	13	
W. H. Hodgkins		2												
A. T. Ireland	1	2	3	4				8	9			12		14
L. W. Jones	1	2	3	4		6		8	9	10	11	12		14
B. E. Kelley		2												
H. M. King								8						
K. E. Kissell		2	3	4		6		8	9	10	11	12	13	14
H. H. Kretschmer	1	2	3						9	10	11			
L. Larmore								8	9			12		
W. A. La Rosa					5	6								
A. L. Lavery	1	2												
E. R. Leslie				4			7							
P. J. Macar	1		3			6		8	9		11	12		14
H. T. Mantis	1		3					8	9		11	12		
R. E. Miller	1	2	3					8	9	10	11	12		14
S. E. Miller					5	6								
S. Nathanson				4										
D. Perlman								8	9			12		
D. E. Reese						6								
G. Righini	1	2	3	4		6		8	9	10	11	12		14
K. Saffer		2											13	14
D. H. Smith										10	11			
H. J. Smith		2												
S. M. Smith	1	2	3	4		6		8	9	10	11	12	13	14
E. W. Steffen			3											
R. E. Stockhausen	1	2	3	4		6		8	9	10	11	12	13	
C. Sykes				4										
J. Thorwaldsen	1													
R. A. Torrey	1	2	3	4		6		8	9	10	11	12	13	
J. H. Waddell								8	9	10	11	12		14
M. Waldmeier	1	2	3	4				8	9	10		12		14
J. M. Weldon	1													
J. L. Whittaker	1	2	3	4	5	6		8	9	10	11	12	13	14
G. Wyntjes	1													
M. S. Young				4										

TABLE VI.- 60 C/S LOAD DISTRIBUTION DURING ECLIPSE INTERCEPT

60 c/s converter		Current load	Experimental stations
Position number	Serial number		
1	138-1	13.5 a	1, 2, 3, 5, 6, 8
2	136-1	0(11.5 a)[1]	(10, 16)[1]
3	137-1	9.0 a	4,[2] 7, 9, 11, 12, 13
4	133-1	1.5 a	WWVH receiver and time code generator

[1]Station 10 supplied the two film storage refrigerators which used about 3 a; Station 16 supplied the coffee maker, about 8.5 a. These loads were turned off 1/2 hour before second contact.

[2]The Station 4 outlet supplied additional 60 c/s power to Station 1. This alleviated some interference problems.

TABLE VII.- DISCONTINUITIES IN THE TIME CODE GENERATOR OUTPUT DURING TOTALITY

	Absolute time, UT	Length of time interval according to		Change in clock
	Hr min sec	Time code	Uniform chart rate	
Figure 20(a)	21:26:45 21:26:49	4.0 sec (two jumps)	3.2 sec	+0.8 sec
Figure 20(b)	21:27:23.8 24.1	0.3 sec (one jump)	0.0 sec	+0.3
Figure 20(c)	21:27:35 36	1.0 sec one repetition	1.5 sec	-0.50
Figure 20(d)	21:27:41.7 42.1	0.4 sec (one jump)	0.0 sec	+0.4
			net gain of clock	+1.0 sec

TABLE VIII.- CONTACT AND TOTALITY TIMES AS FUNCTIONS OF TIME AND POSITION ERRORS FOR THE ECLIPSE FLIGHT OF 30 MAY 1965 (ADAPTED FROM REF. 4)

Position error, nautical miles		Minutes late at mid-totality			Minutes early at mid-totality		
		-2	-1	0	1	2	3
South	15	21:17:23 21:26:44 561	21:18:12 21:27:23 561	21:19:01 21:28:23 561	21:19:50 21:29:14 564	21:20:39 21:30:05 566	21:21:27[a] 21:30:56[b] 569[c]
South	10	21:17:19 21:26:50 571	21:18:07 21:27:39 572	21:18:56 21:28:29 573	21:19:44 21:29:19 575	21:20:32 21:30:09 577	21:21:20[a] 21:30:59[b] 579[c]
South	5	21:17:18 21:26:54 576	21:18:05 21:27:43 578	21:18:53 21:28:32 579	21:19:41 21:29:22 581	21:20:29 21:30:11 582	21:21:17[a] 21:30:59[b] 582[c]
	0	21:17:19 21:26:55 576	21:18:06 21:27:43 577	21:18:53 21:28:33 580	21:19:40 21:29:22 582	21:20:28 21:30:10 582	21:21:15[a] 21:30:57[b] 582[c]
North	5	21:17:23 21:26:54 571	21:18:08 21:27:42 574	21:18:54 21:28:31 577	21:19:41 21:29:19 578	21:20:29 21:30:06 577	21:21:17[a] 21:30:53[b] 576[c]

Note: This table assumes a ground speed of 490 knots, no cross wind, and a constant sun-bearing flight path. To correct intercept times for actual ground speed, proceed as follows:

(1) If actual ground speed is greater than 490 knots, subtract 0.5 second (per knot over 490) from time of second contact; add 0.5 second (per knot over 490) to time of third contact.

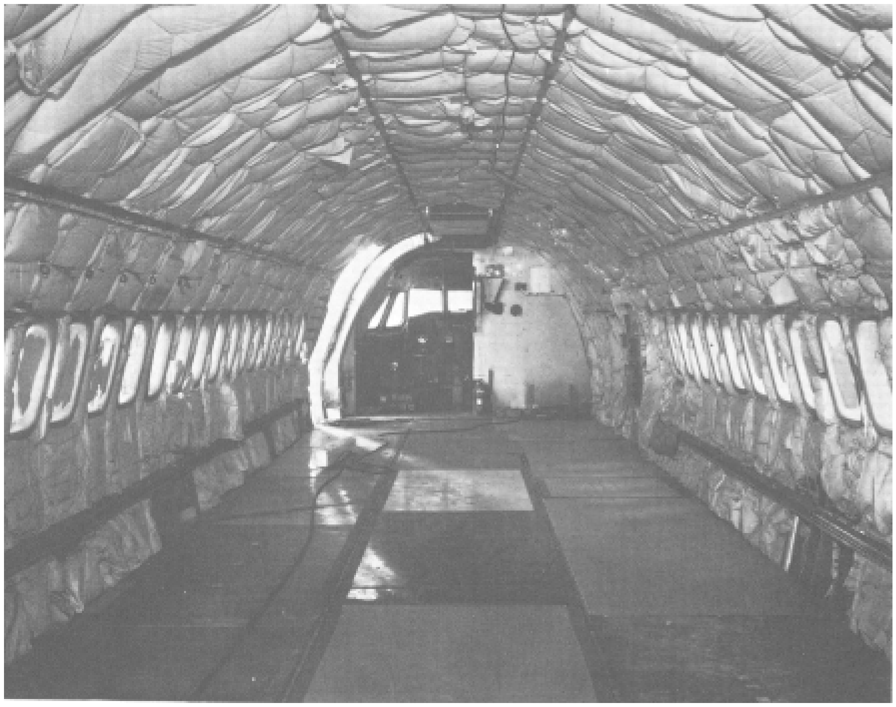
(2) If actual ground speed is less than 490 knots, add 0.5 second (per knot over 490) to time of second contact; subtract 0.5 second (per knot over 490) from time of third contact.

[a]Second contact, UT [b]Third contact, UT [c]Totality duration, seconds

TABLE IX.- AIRCRAFT POSITIONS AND TIMES AT SECOND AND THIRD CONTACTS
(See also fig. 12)

B (second contact):
01° 48′ S
132° 04′ W
$21^h\ 20^m\ 39^s$ UT(±2 sec)

E (third contact):
01° 31′ S
130° 44′ W
$21^h\ 30^m\ 21^s$ UT(±2 sec)



(a) Looking forward. A-34471-157

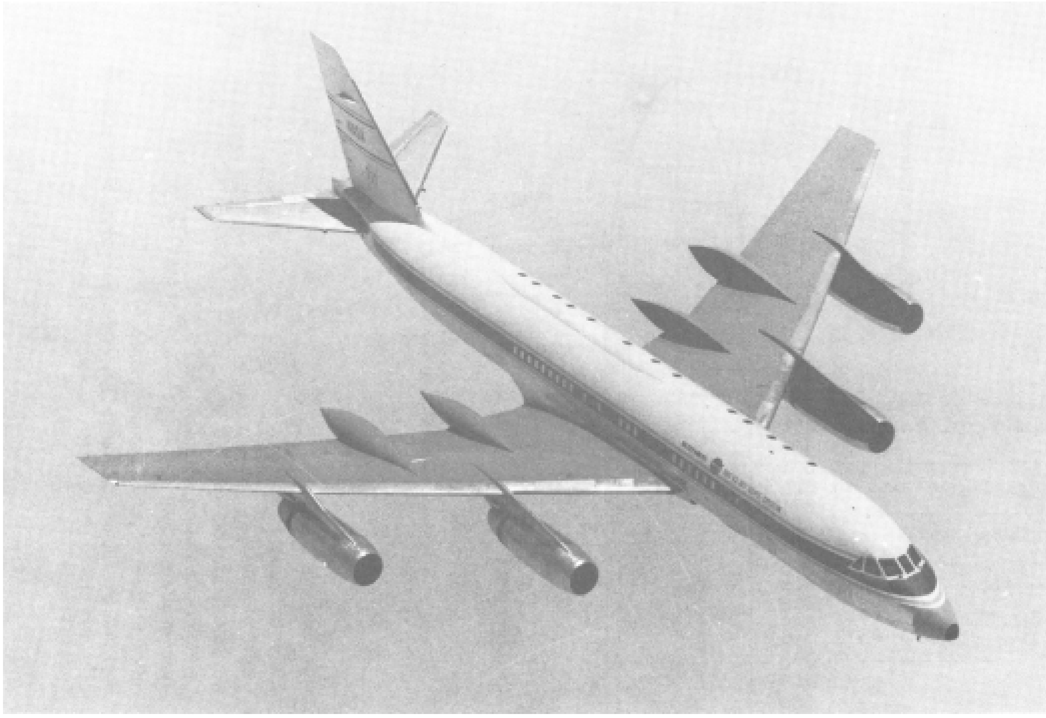
(b) Looking aft. A-34471-156

Figure 1.- Aircraft interior at time of purchase (October 1964).

(a) Looking forward. A-34471-151

(b) Looking aft. A-34471-149

Figure 2.- Aircraft interior after modifications (May 1965).



A-34471-25

A-34471-54

Figure 3.- Overall views of the expedition aircraft. Note in particular the 13 overhead ports. The black paint on the left wing pods and nacelles was intended to minimize reflections to the overhead ports.

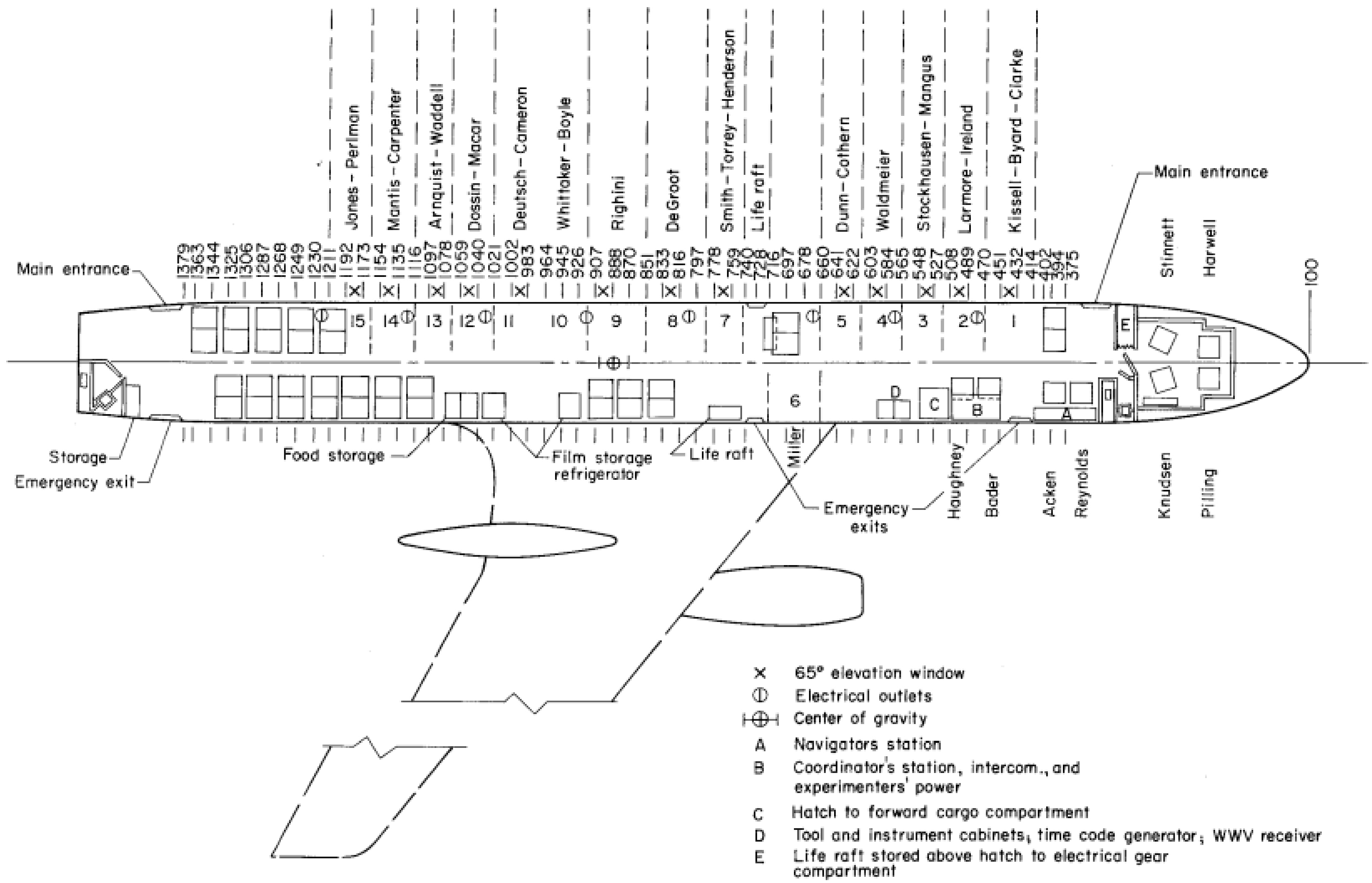


Figure 4.- Aircraft floor plan for the 1965 Eclipse Expedition.

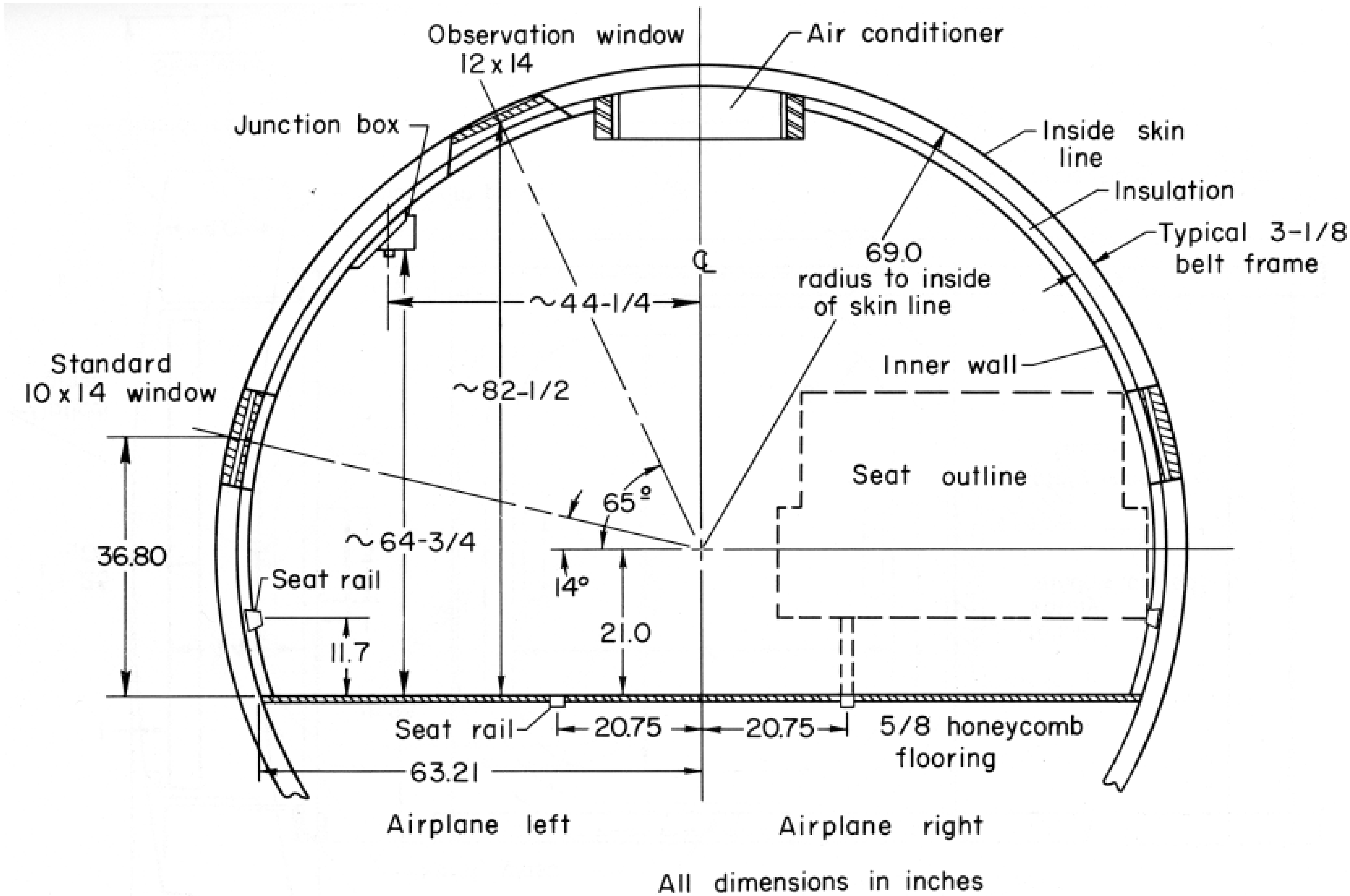


Figure 5.- Cabin cross section.

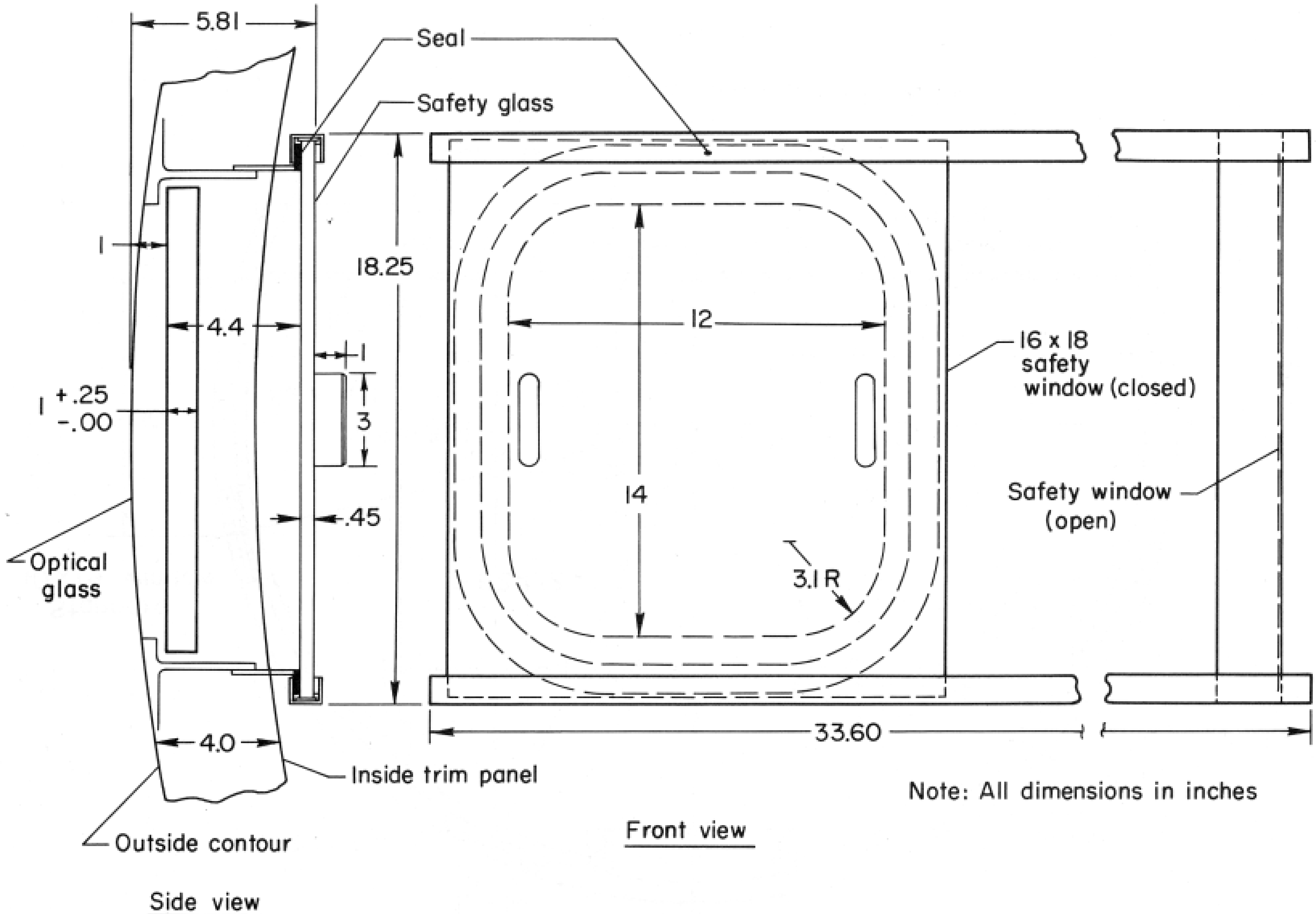


Figure 6.- Special 65° view ports and safety windows.

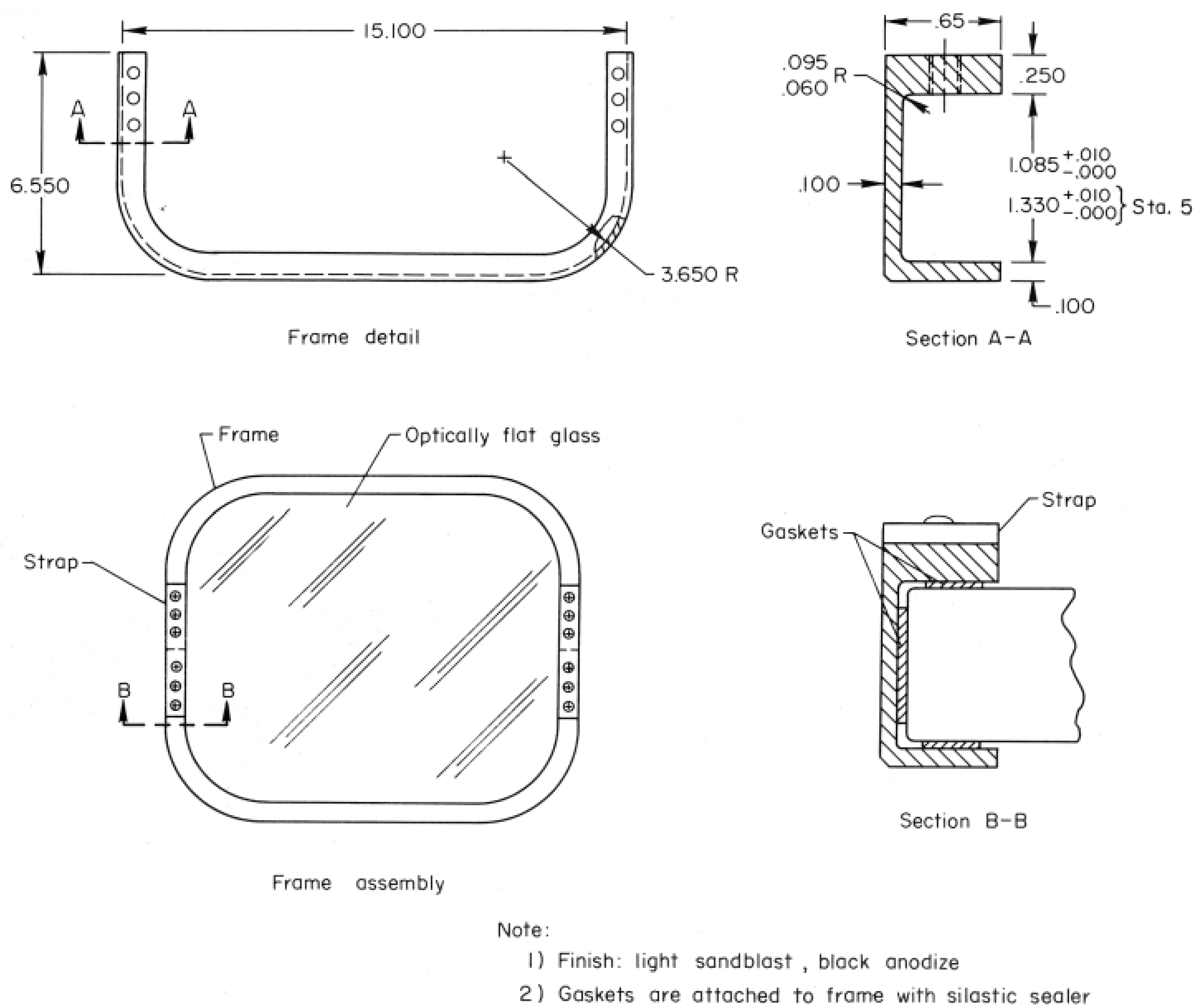


Figure 7.- Frames for optical windows.

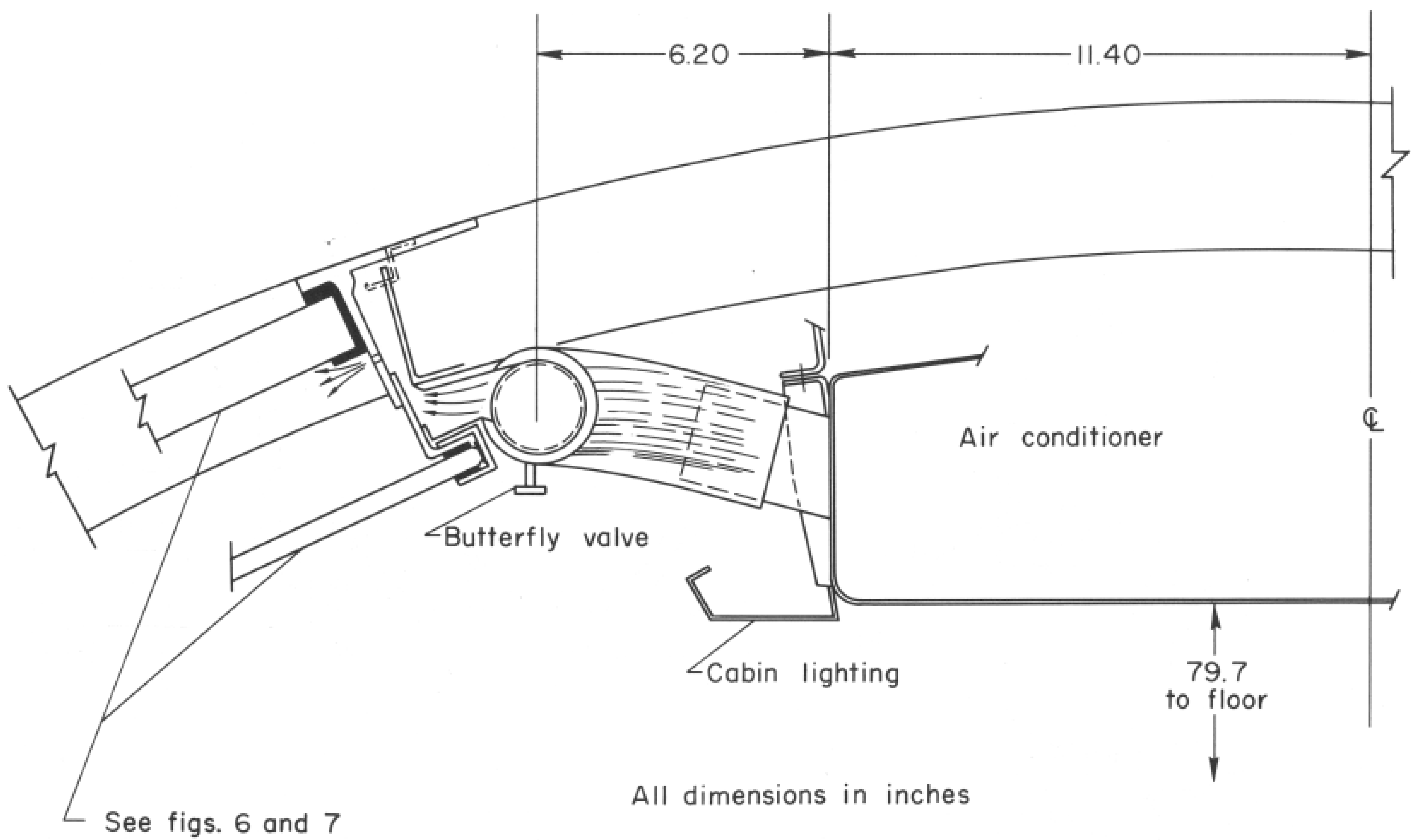
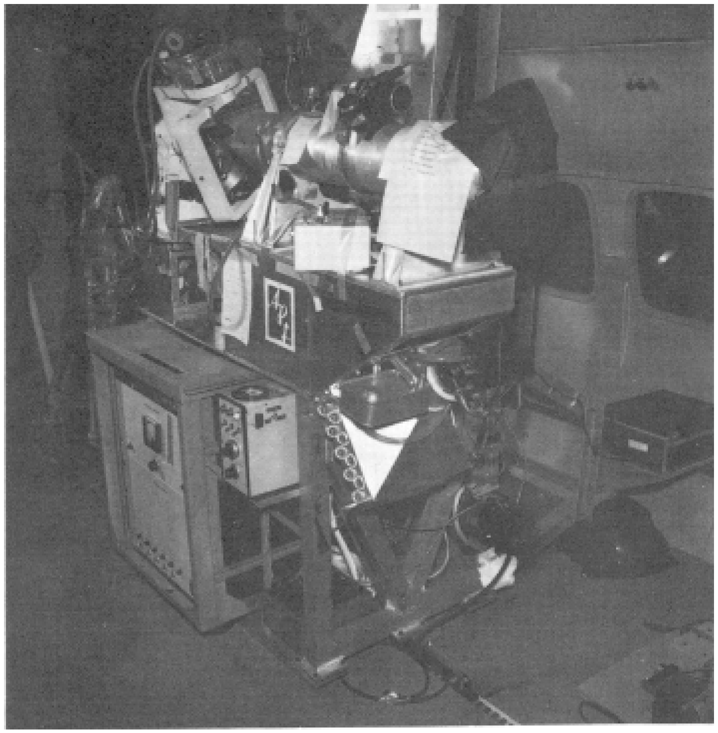
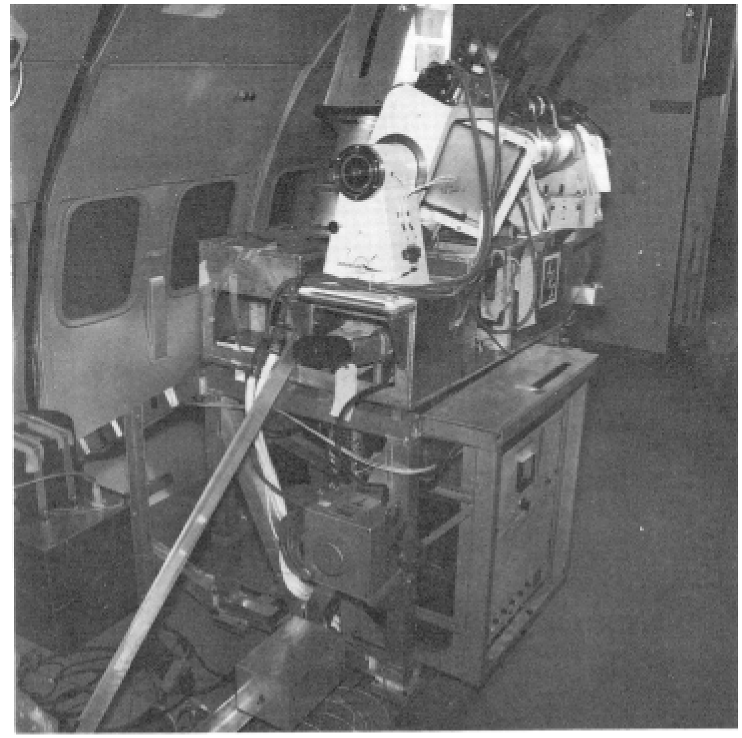


Figure 8.- General layout of lighting, air conditioning, and defrosting systems.



A-34471
Sta. 1-11

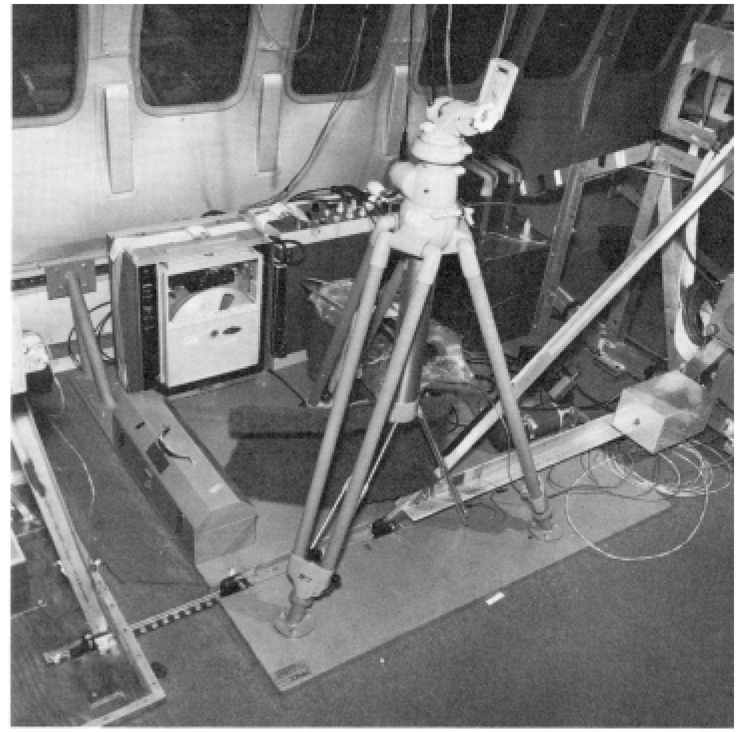


A-34471
Sta. 1-10

(a) Station 1. U.S. Air Force, Aerospace Research Laboratory

Figure 9.- Experimenter’s equipment.

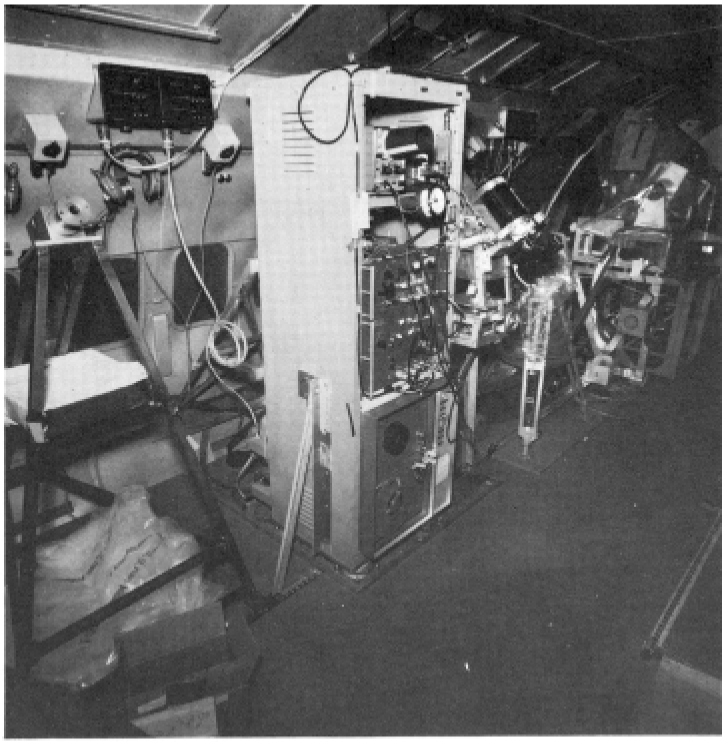
A-34471
Sta. 2-4



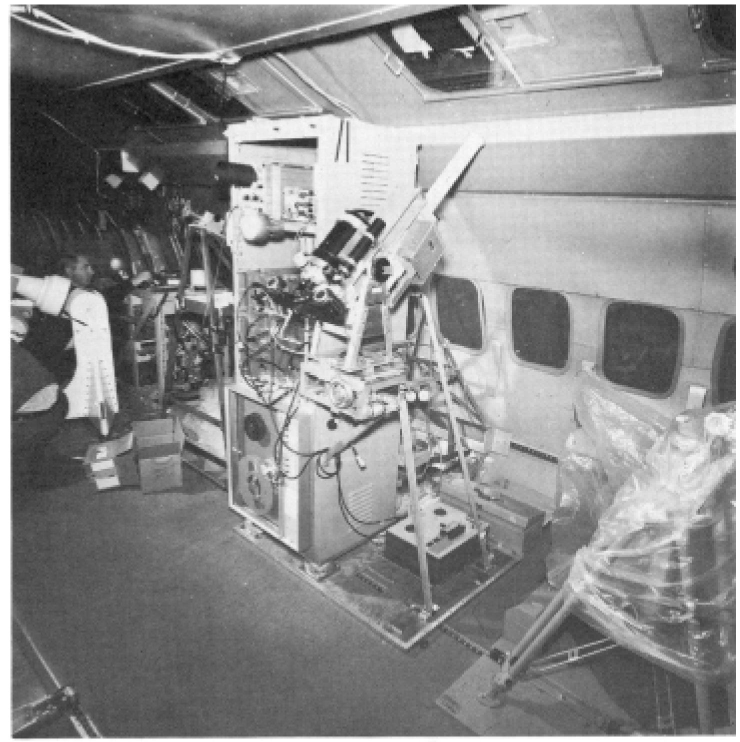
A-34471
Sta. 2-5

(b) Station 2. Douglas Aircraft Company, Inc.

Figure 9.- Continued.



A-34471
Sta. 3-9

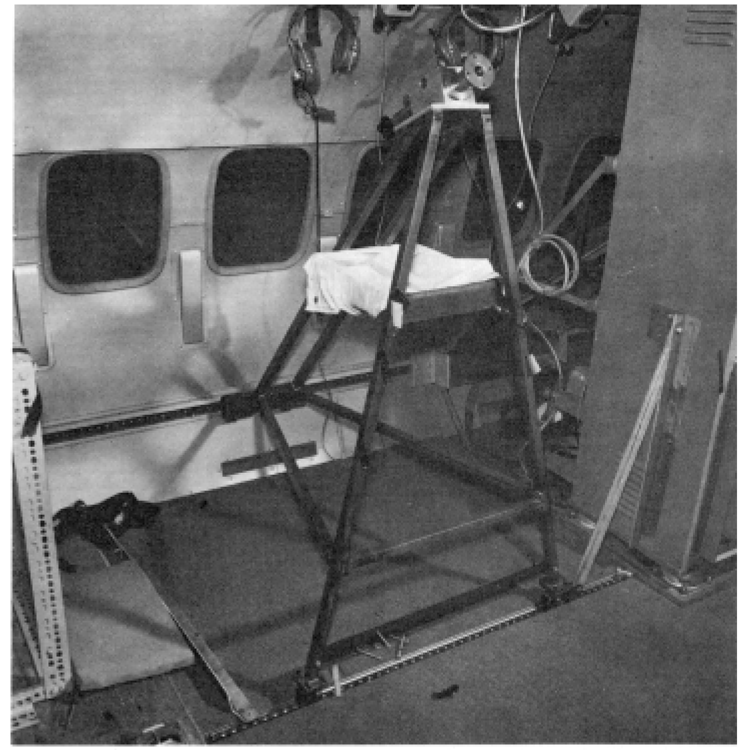


A-34471
Sta. 3-10

(c) Station 3. NASA-Goddard Space Flight Center.

Figure 9.- Continued.

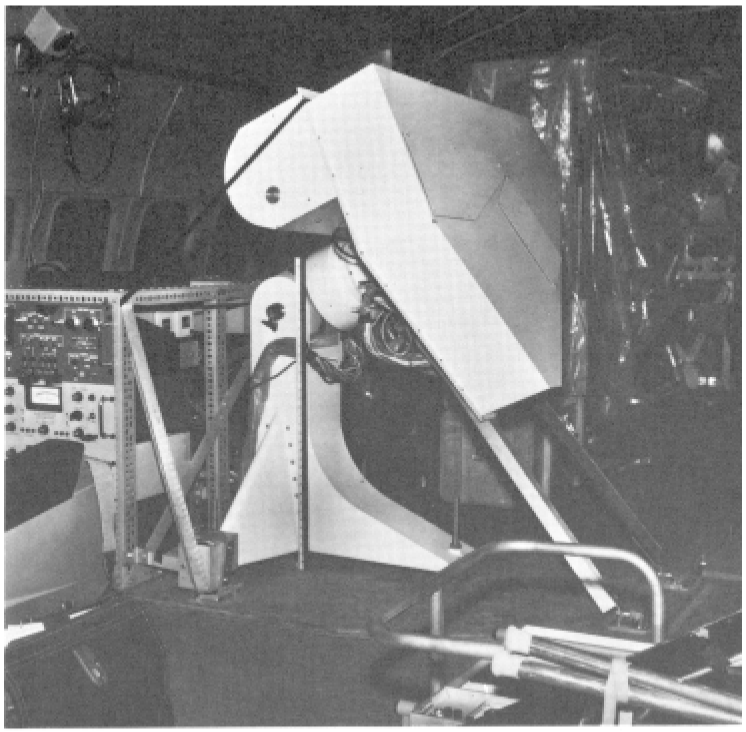
A-34471
Sta. 4-5

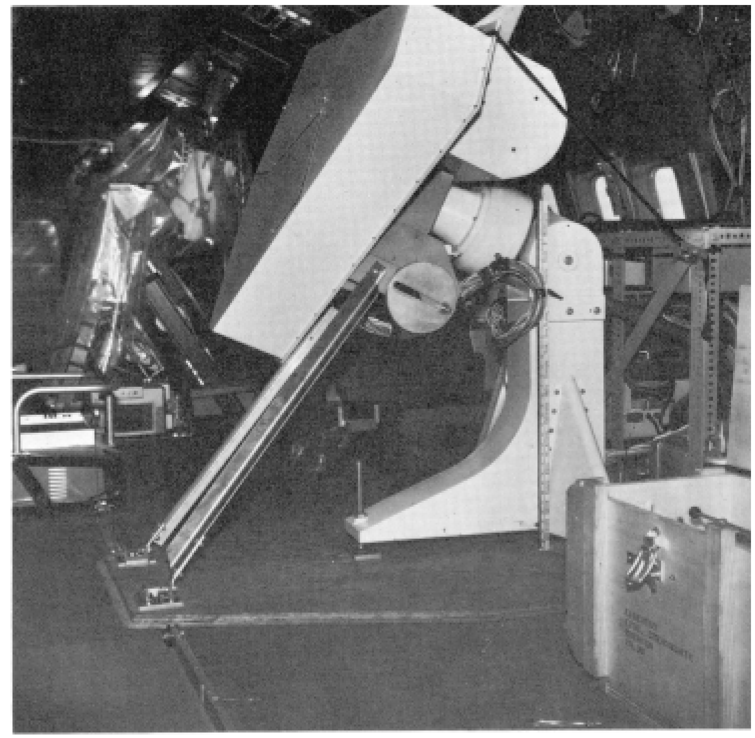


A-34471
Sta. 4-2

(d) Station 4. Swiss Federal Observatory, Zurich.

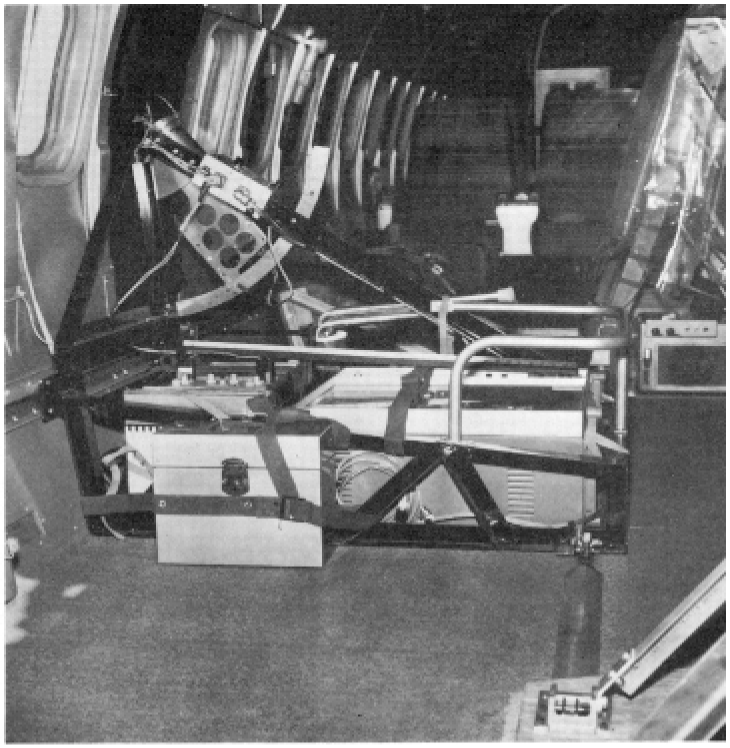
Figure 9.- Continued.


A-34471
Sta. 5-5


A-34471
Sta. 5-6

(e) Station 5. U. S. Air Force, Sacramento Peak Observatory.

Figure 9.- Continued.

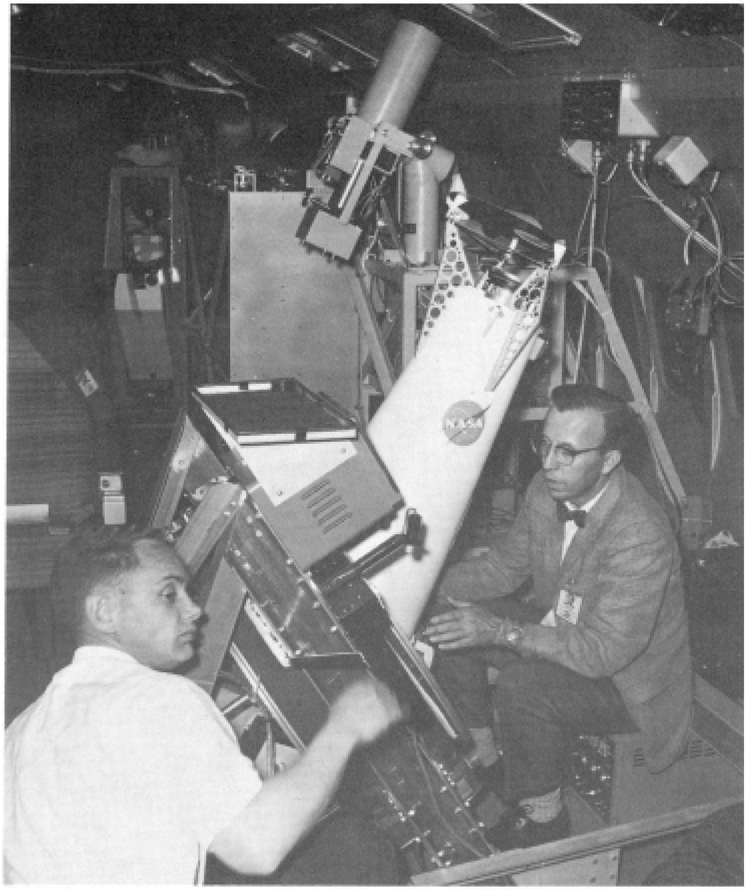


A-34471
Sta. 6R-10

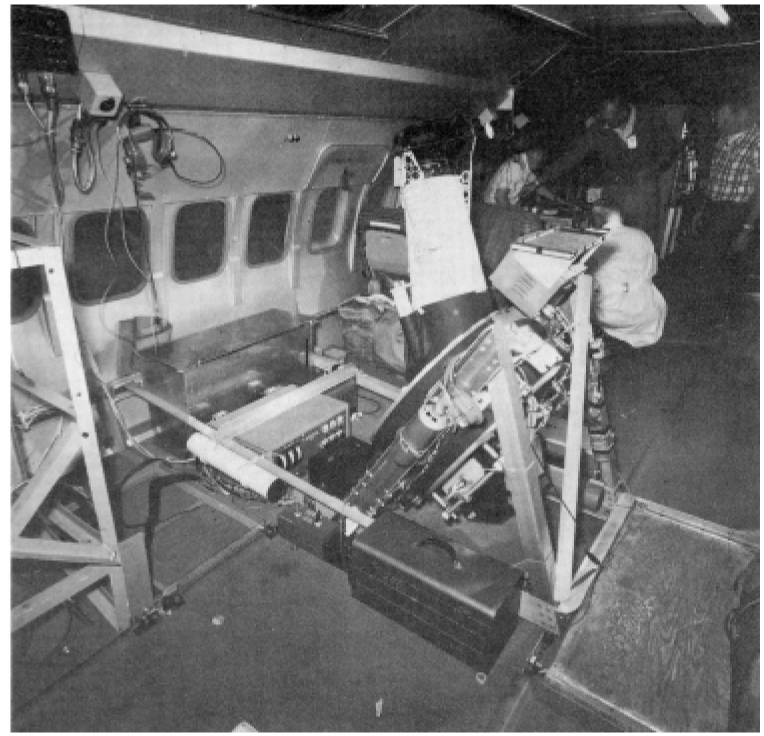
A-34471
Sta. 6R-8

(f) Station 6. Johns Hopkins University.

Figure 9.- Continued.



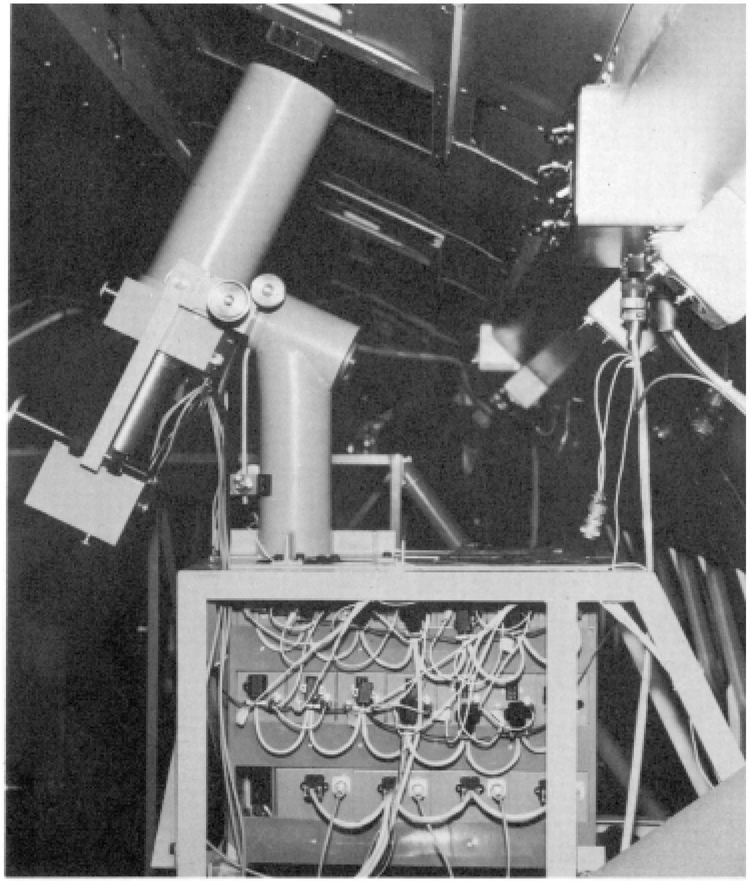
A-34471
Sta. 7-3



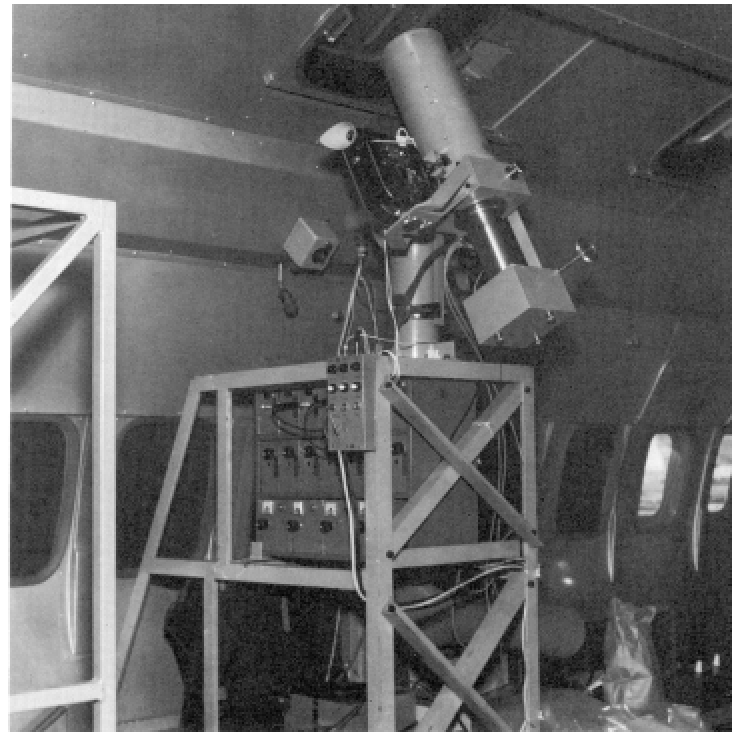
A-34471
Sta. 7-15

(g) Station 7. NASA-Ames Research Center.

Figure 9.- Continued.



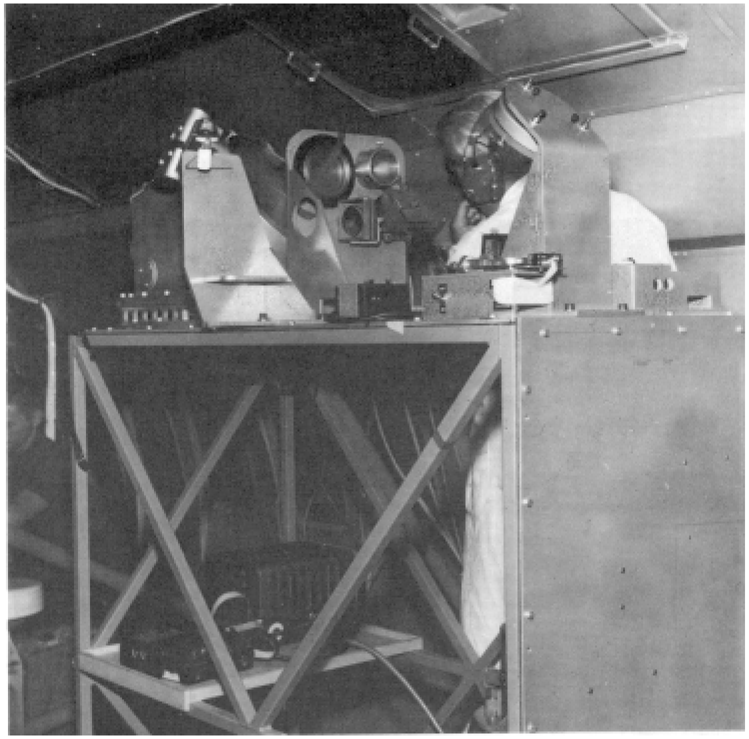
A-34471
Sta. 8-9



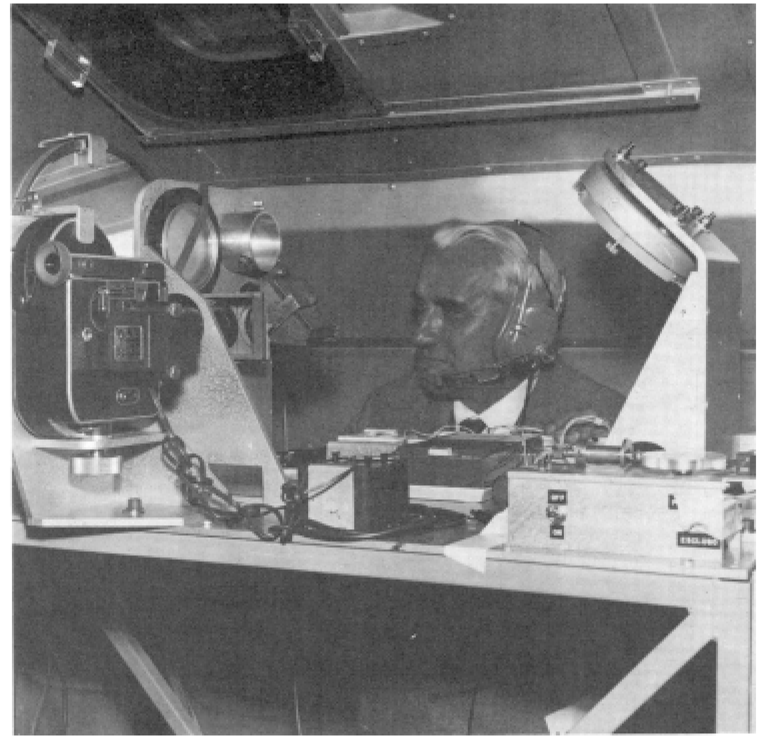
A-34471
Sta. 8-5

(h) Station 8. Sonnenborgh Observatory, Utrecht.

Figure 9.- Continued.



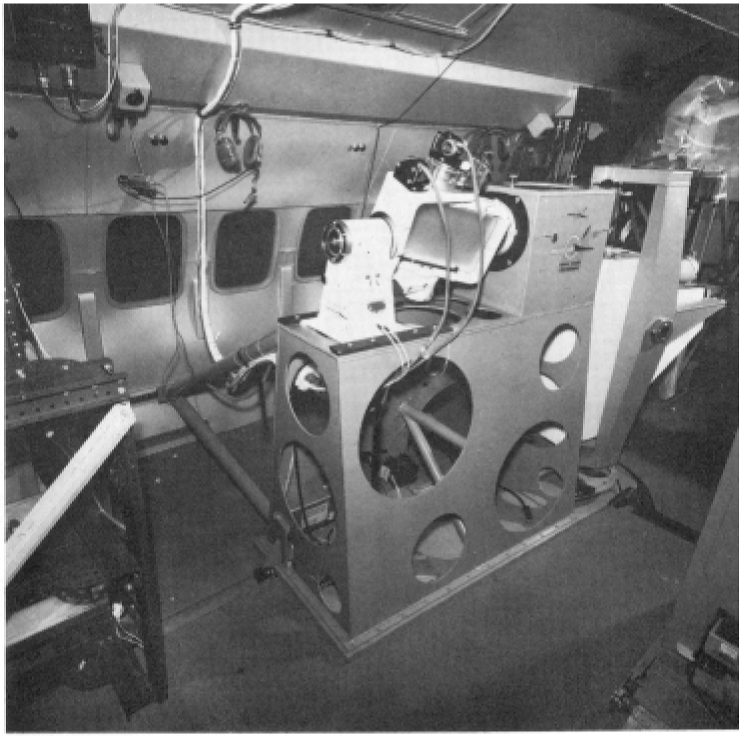
A-34471
Sta. 9-2



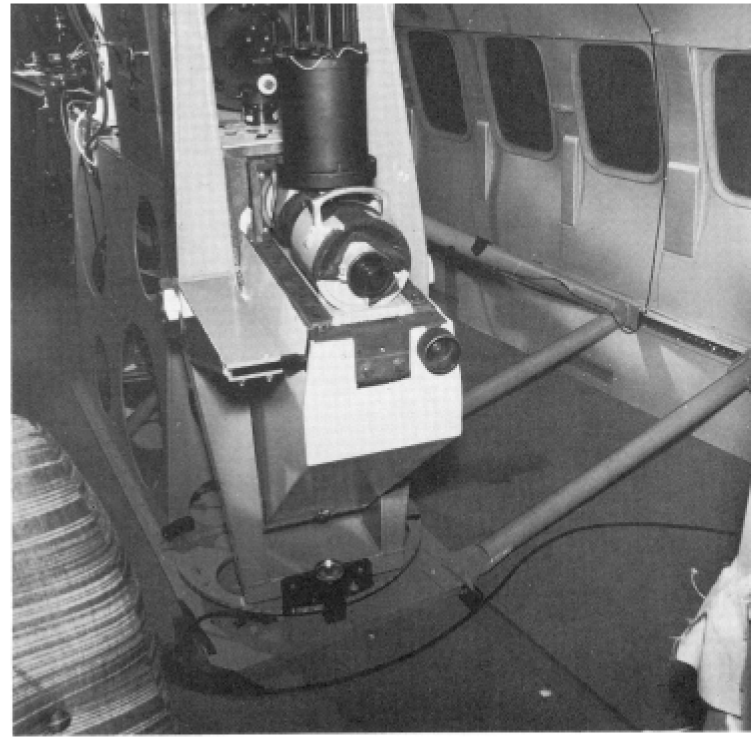
A-34471
Sta. 9-4

(i) Station 9. Arcetri Observatory.

Figure 9.- Continued.



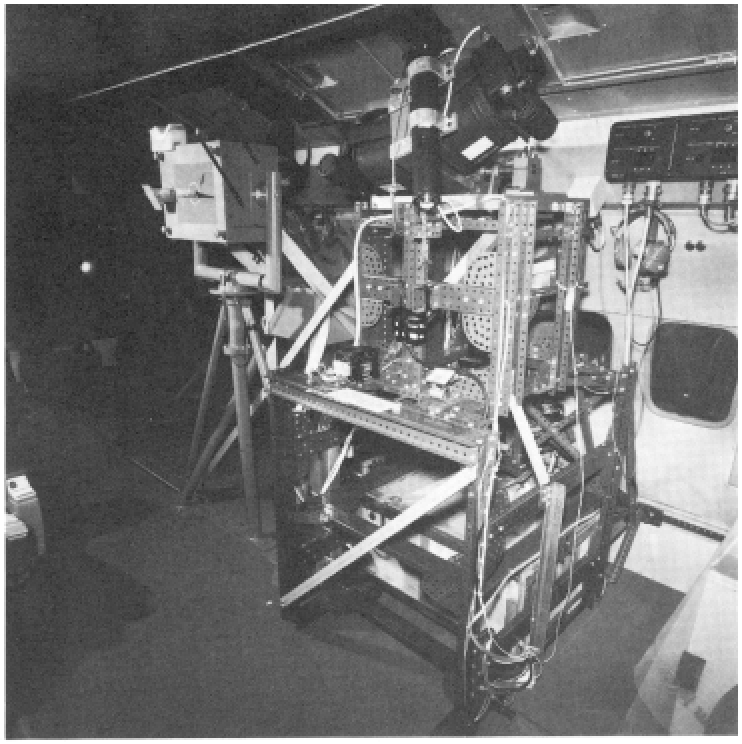
A-34471
Sta. 11-13



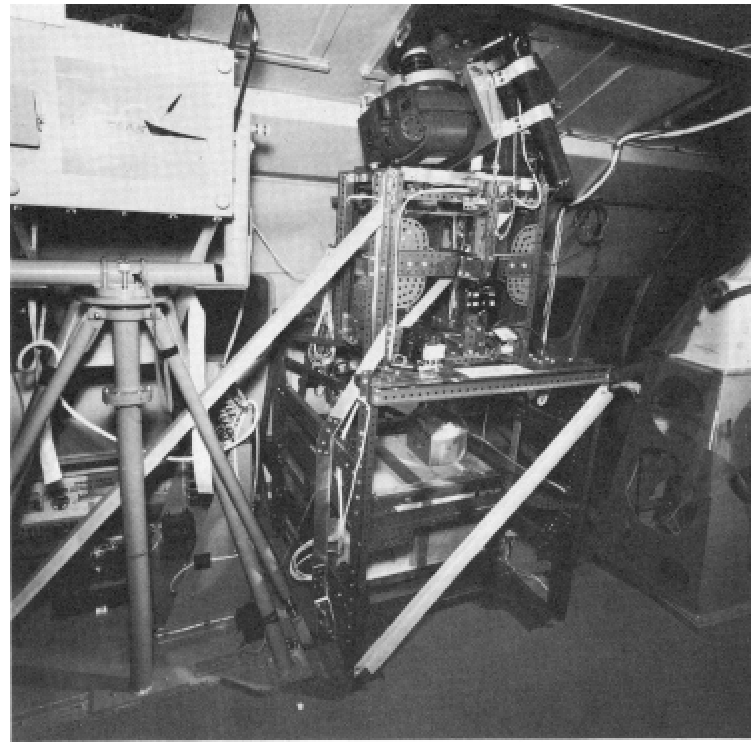
A-34471
Sta. 11-14

(j) Stations 10-11. Mount Wilson-Palomar Observatories and Douglas Aircraft Company.

Figure 9.- Continued.



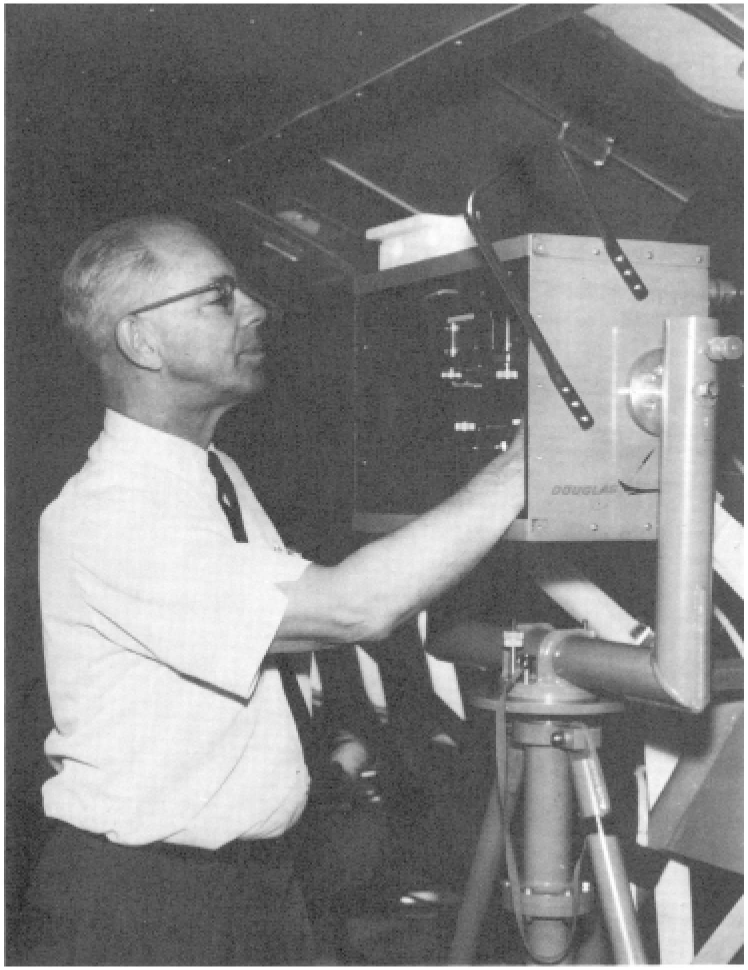
A-34471
Sta. 12-9



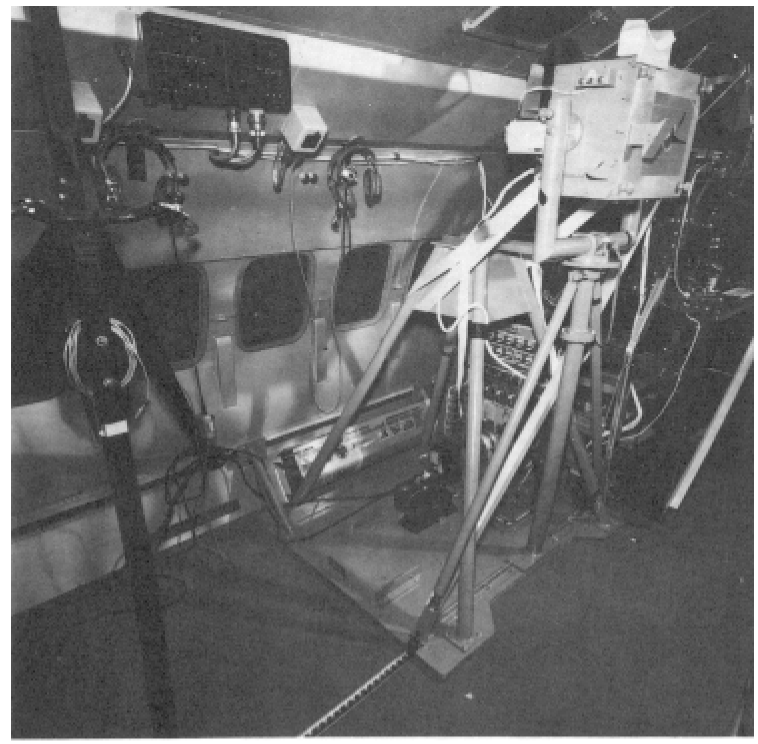
A-34471
Sta. 12-10

(k) Station 12. University of Liege.

Figure 9.- Continued.



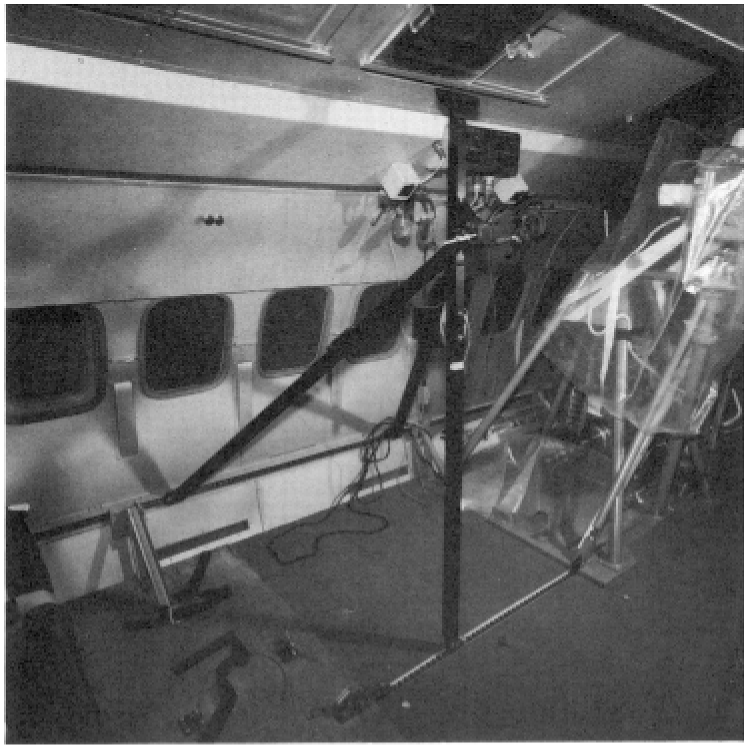
A-34471
Sta. 13-7



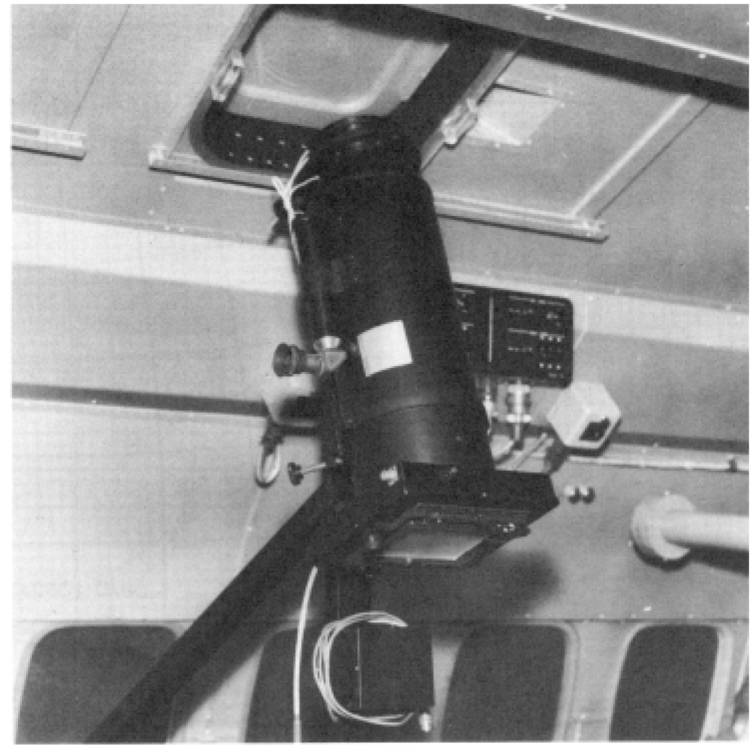
A-34471
Sta. 13-3

(l) Station 13. Douglas Aircraft Company.

Figure 9.- Continued.



A-34471
Sta. 14-12



A-34471
Sta. 14-10

(m) Station 14. University of Minnesota and NASA-Manned Spacecraft Center.

Figure 9.- Concluded.

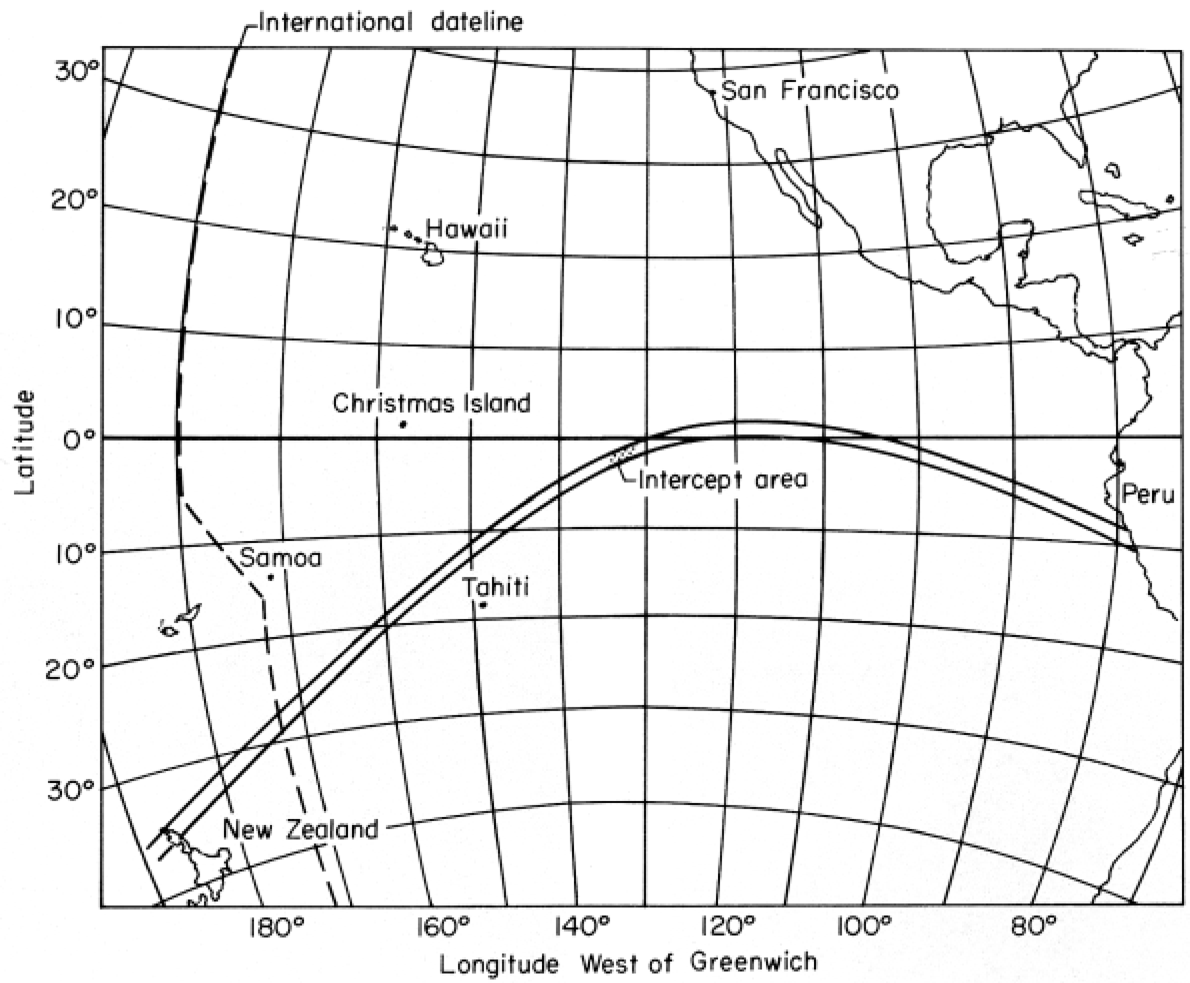


Figure 10.- The path of totality of the total solar eclipse of 30 May 1965.

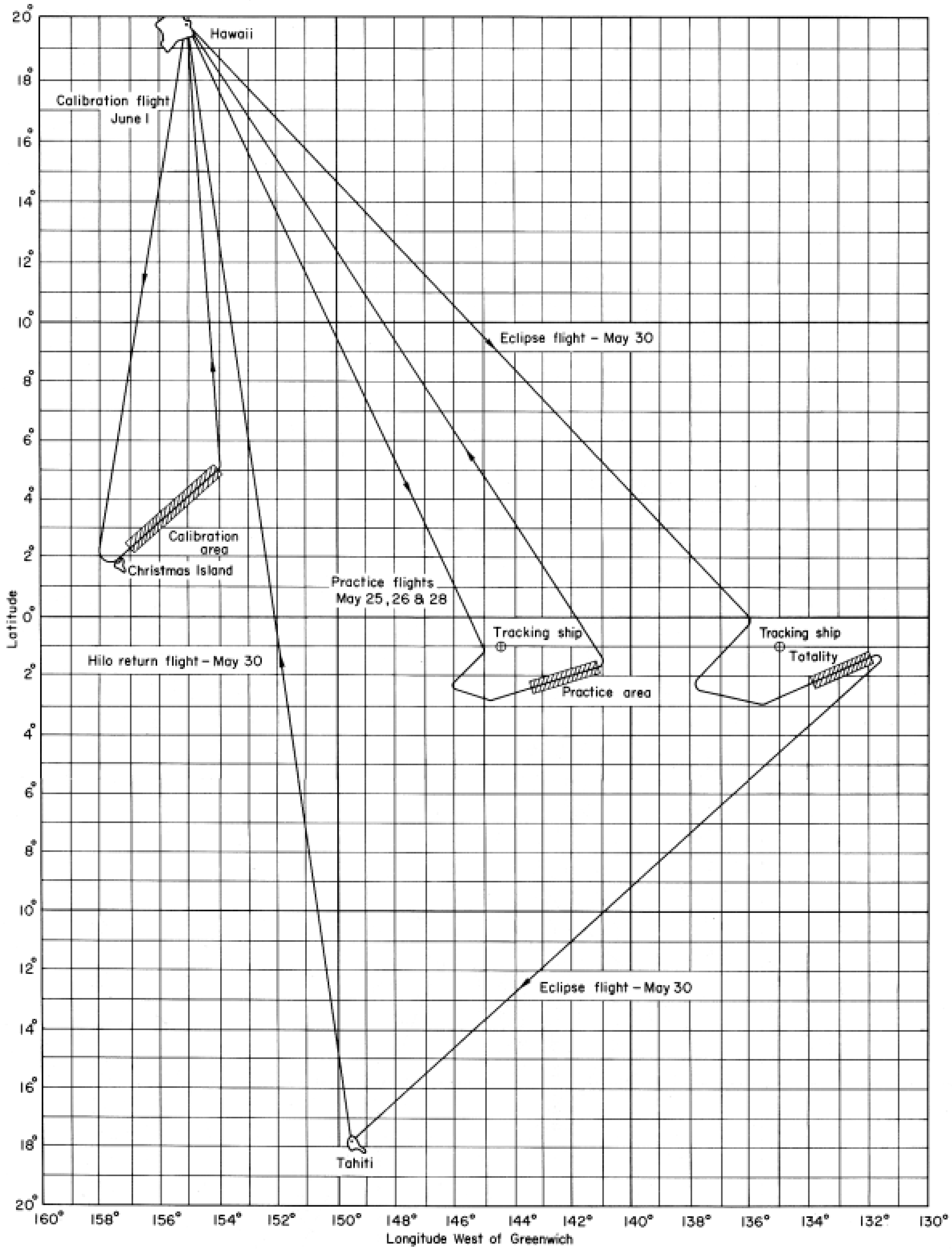


Figure 11.- Flight paths for all flights from Hilo, Hawaii.

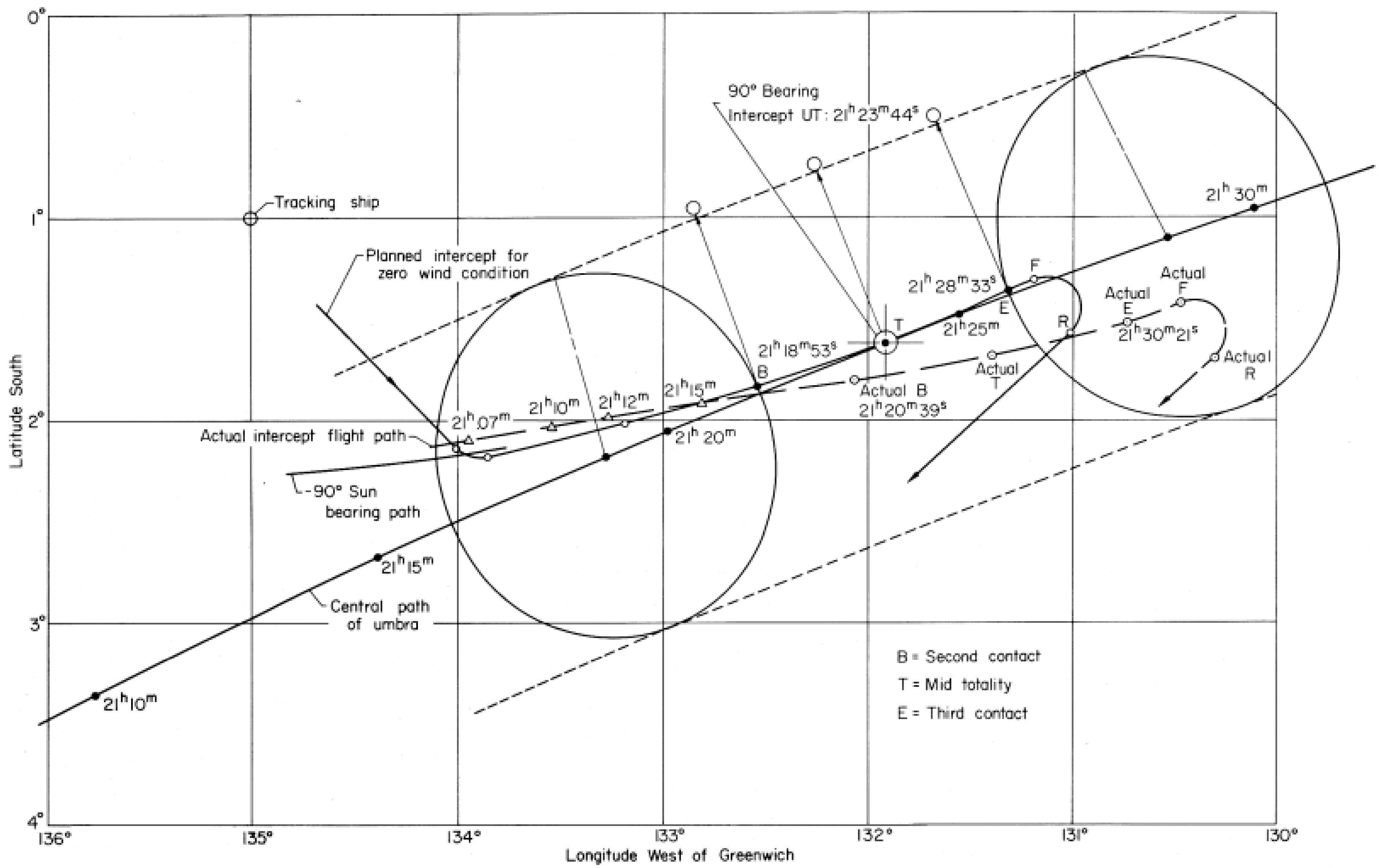


Figure 12.- Expanded map of eclipse intercept areashowing planned and actual flight paths and times. See also table IX.

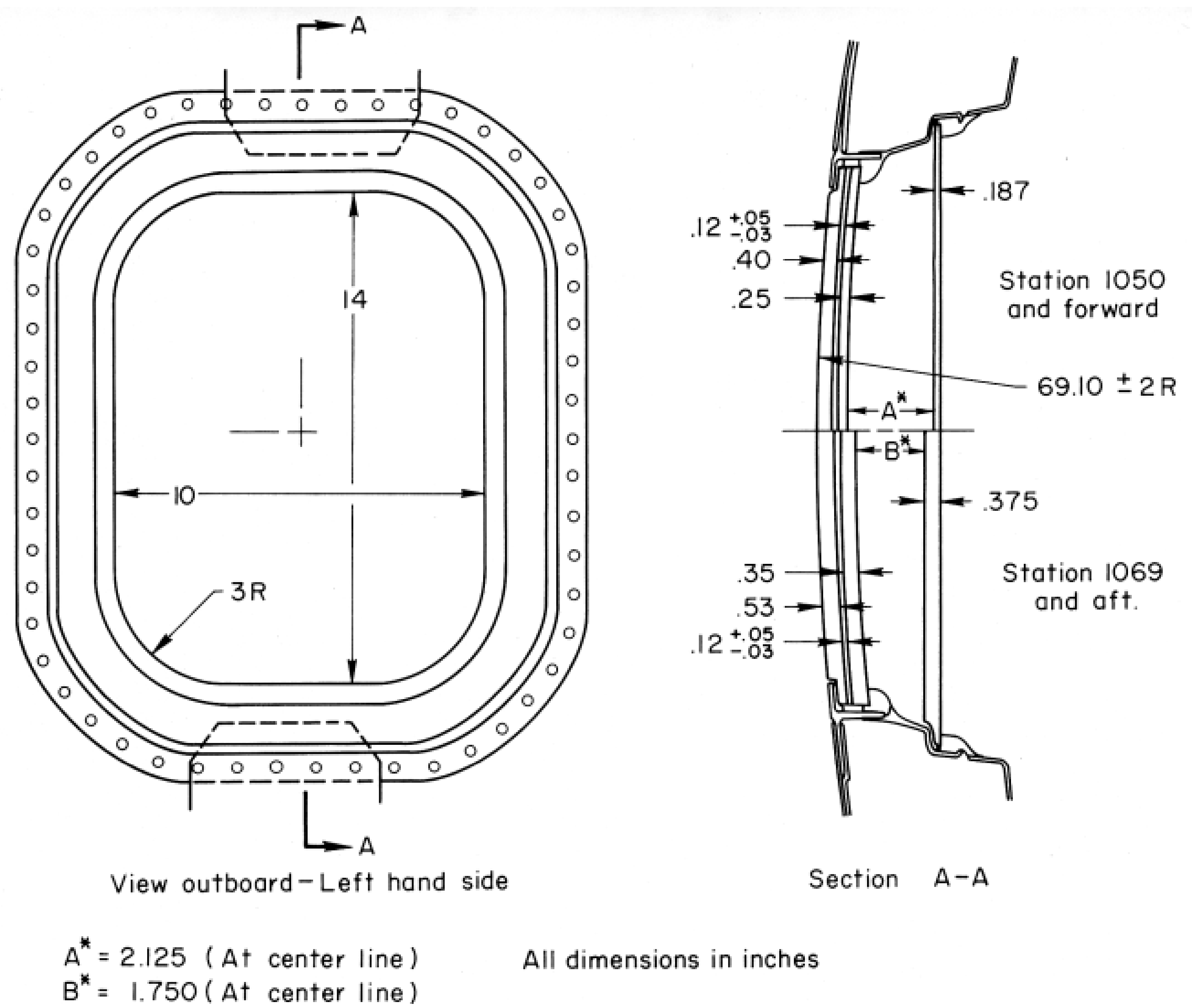


Figure 13.- Construction of passenger windows. See figure 4 for fuselage station numbers, and figure 5 for location in cabin cross section.

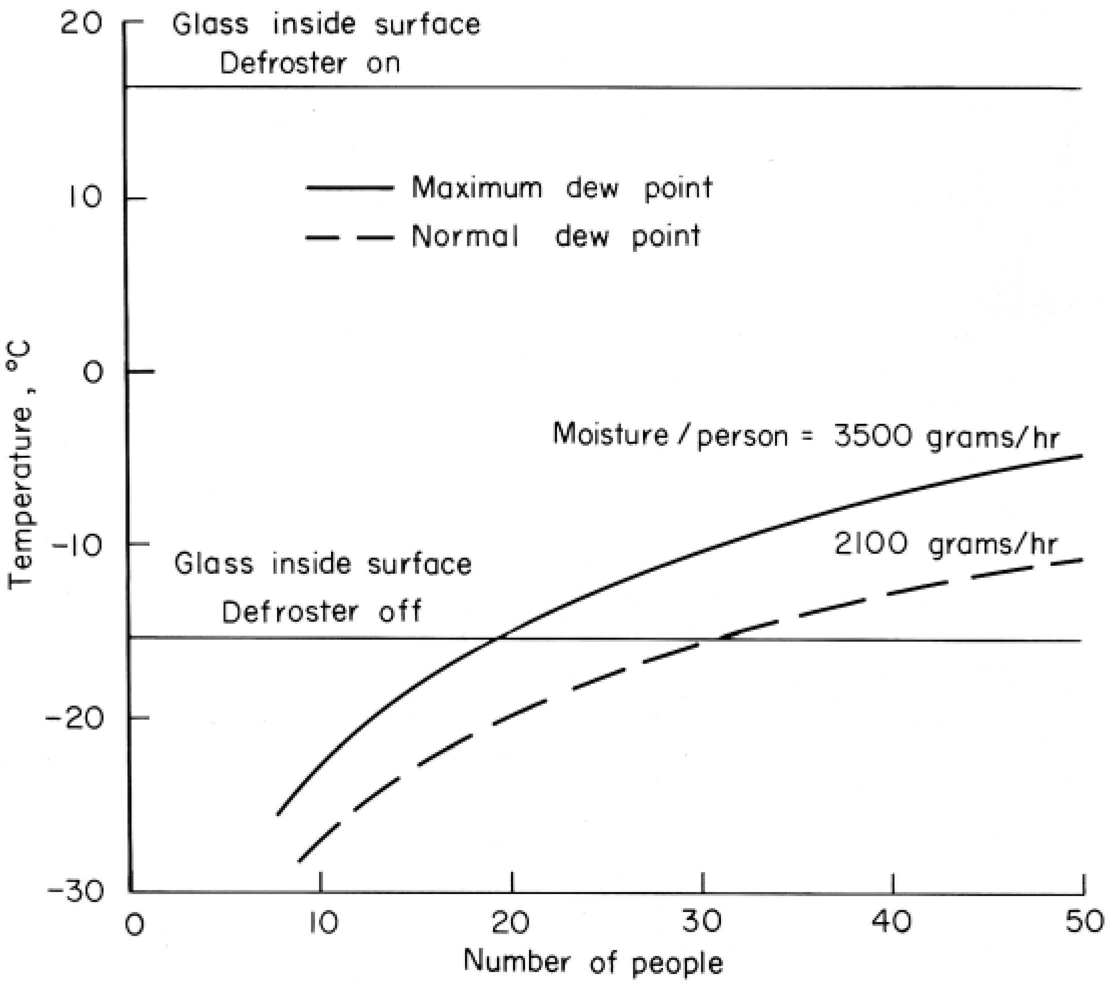
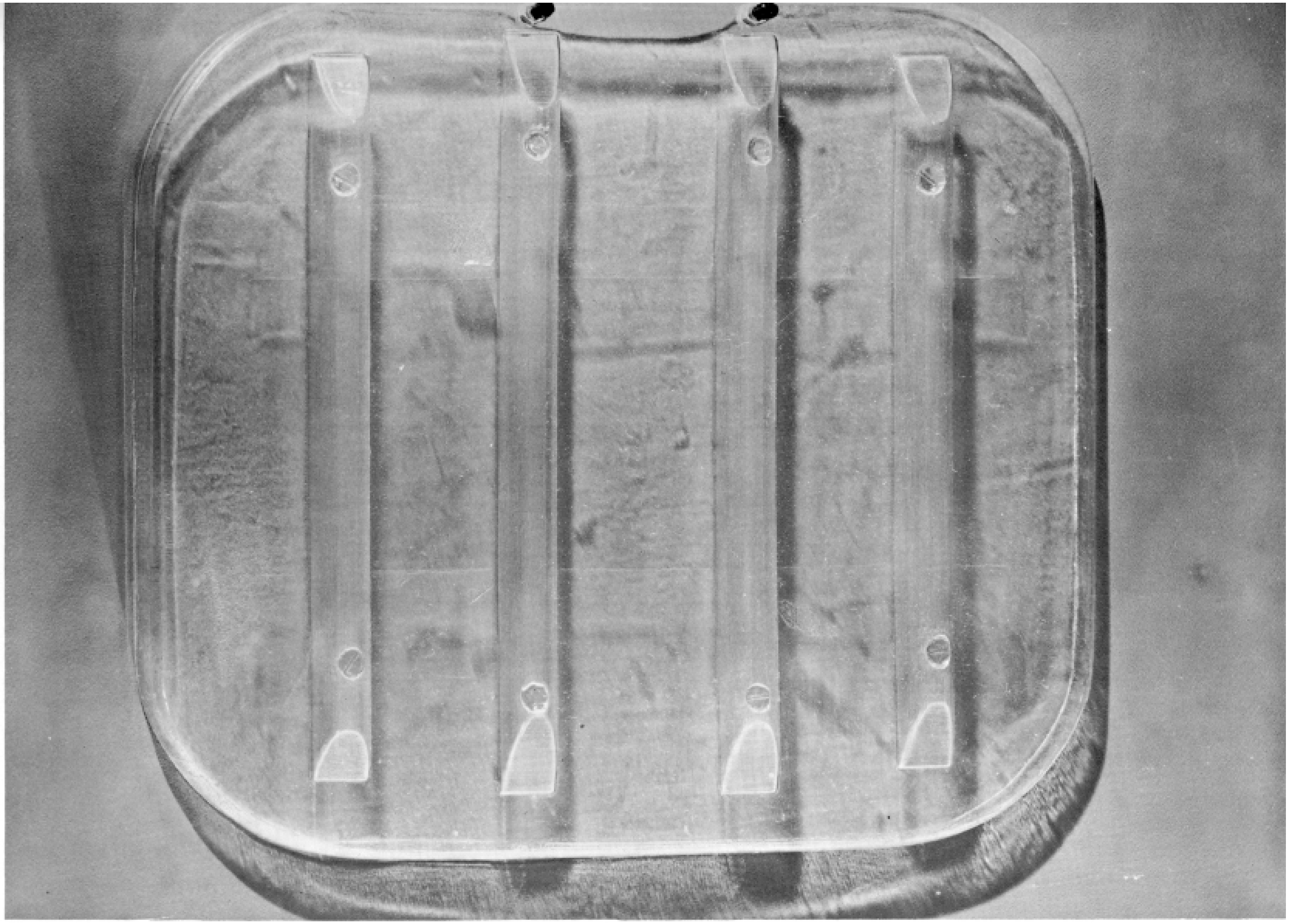
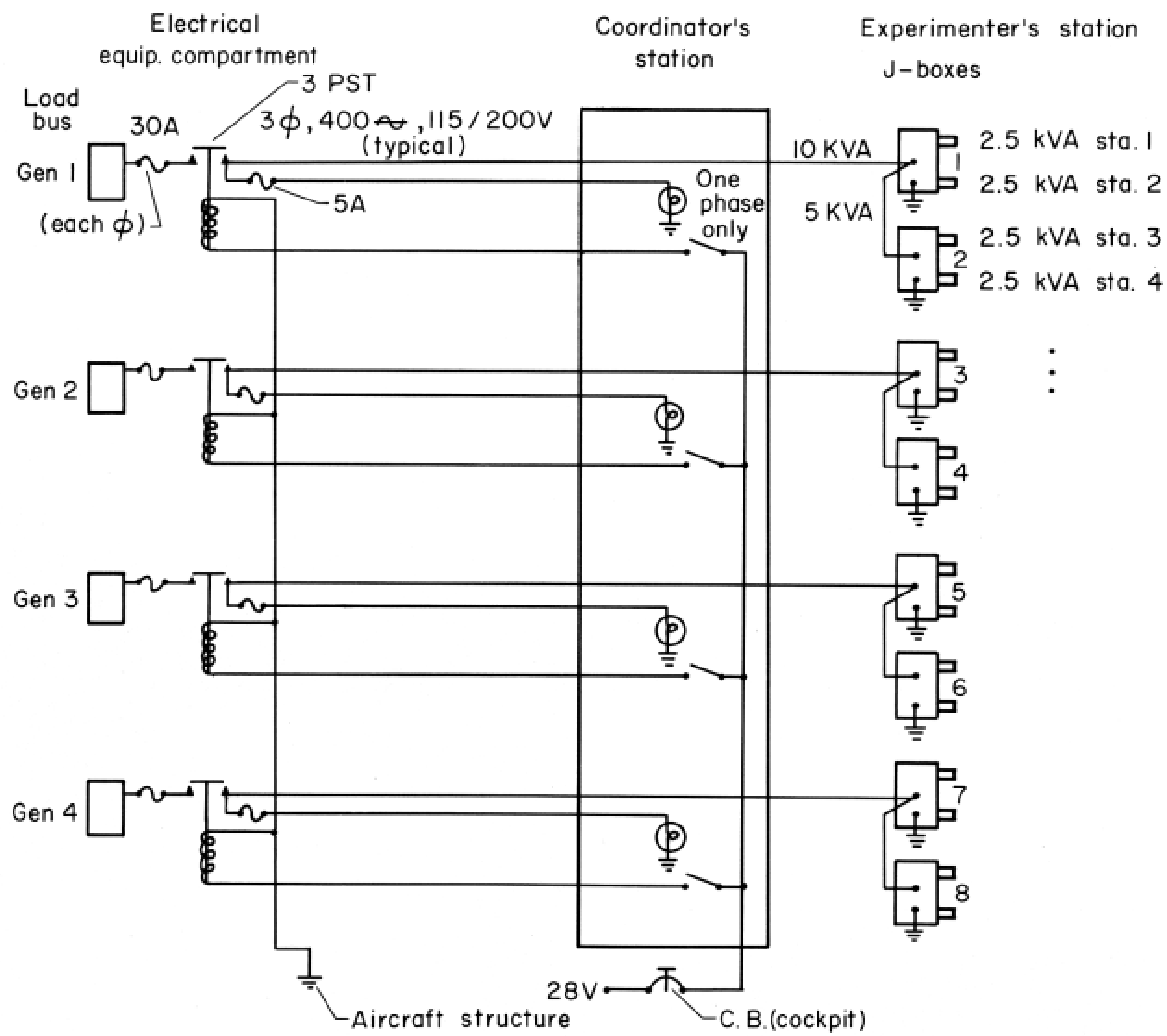


Figure 14.- Calculated effectiveness of the defrosting system, assuming: 41,000 ft altitude, ambient temperature -65° C, Mach number 0.91, air conditioner flow 120 lb/min, defroster flow 3 lb/min per window.



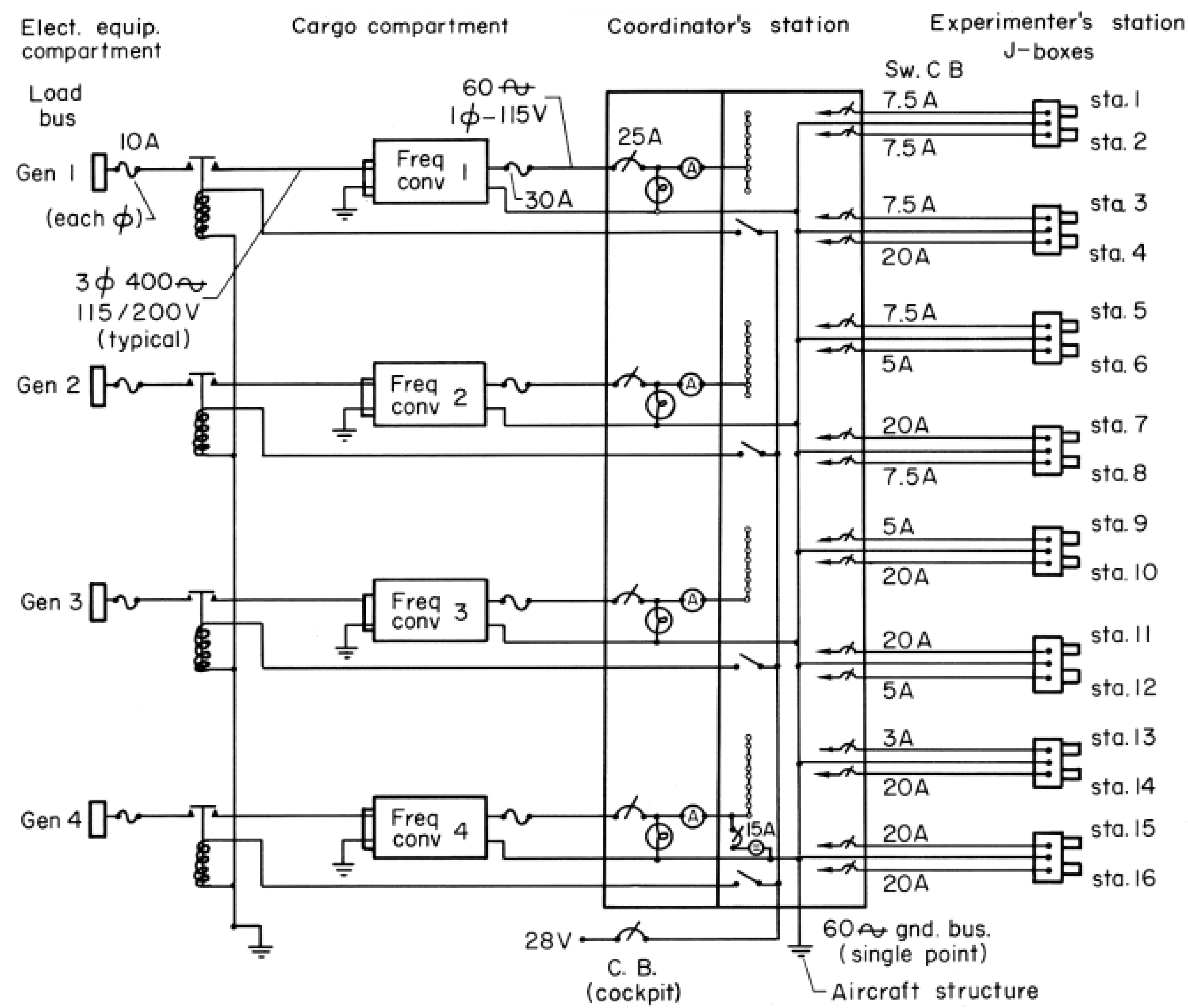
A-34471-155

Figure 15.- External plastic cover for optical windows.



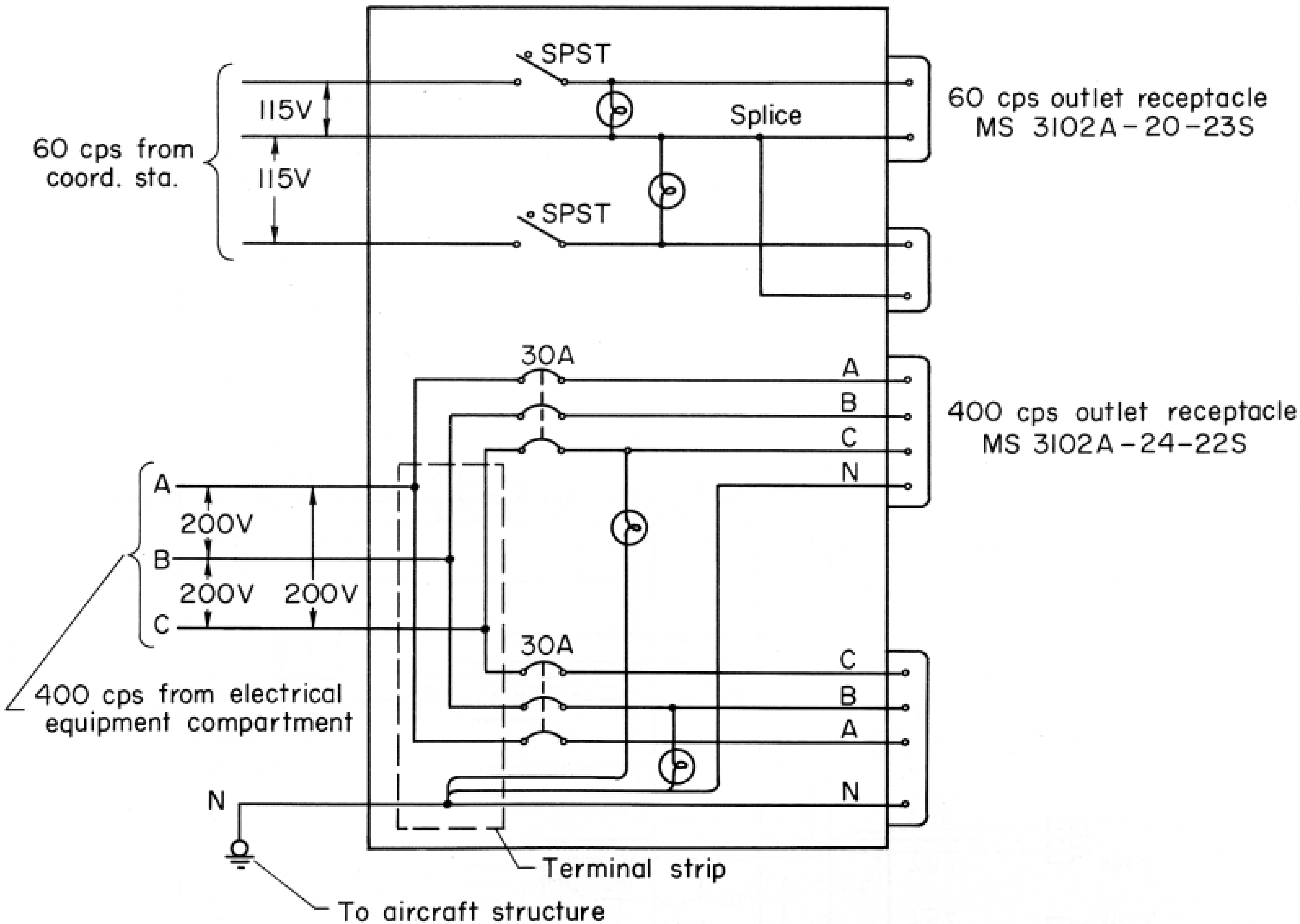
(a) 400 c/s distribution.

Figure 16.- Schematic diagrams of the experimenters' electrical power distribution system.



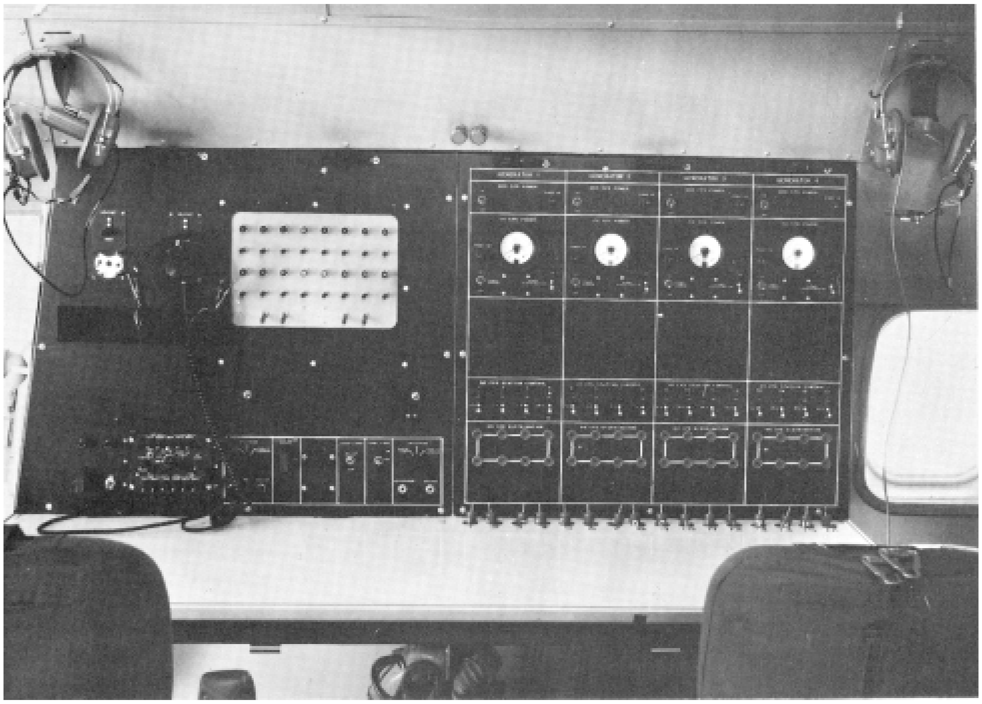
(b) 60 c/s distribution.

Fiaure 16.- Continued.



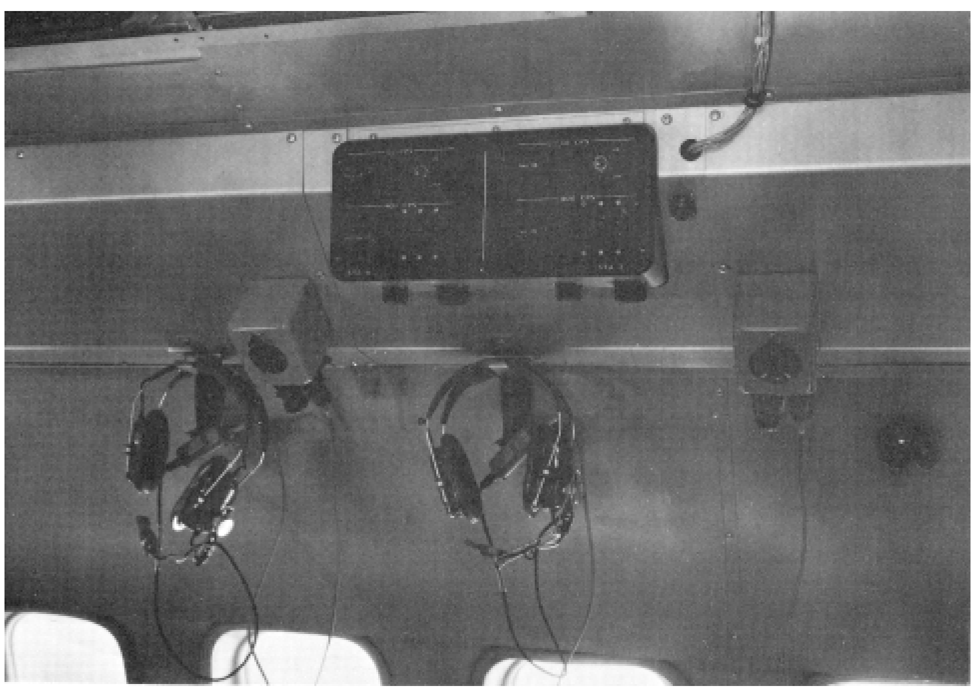
(c) Fuselage junction boxes.

Figure 16.- Concluded.



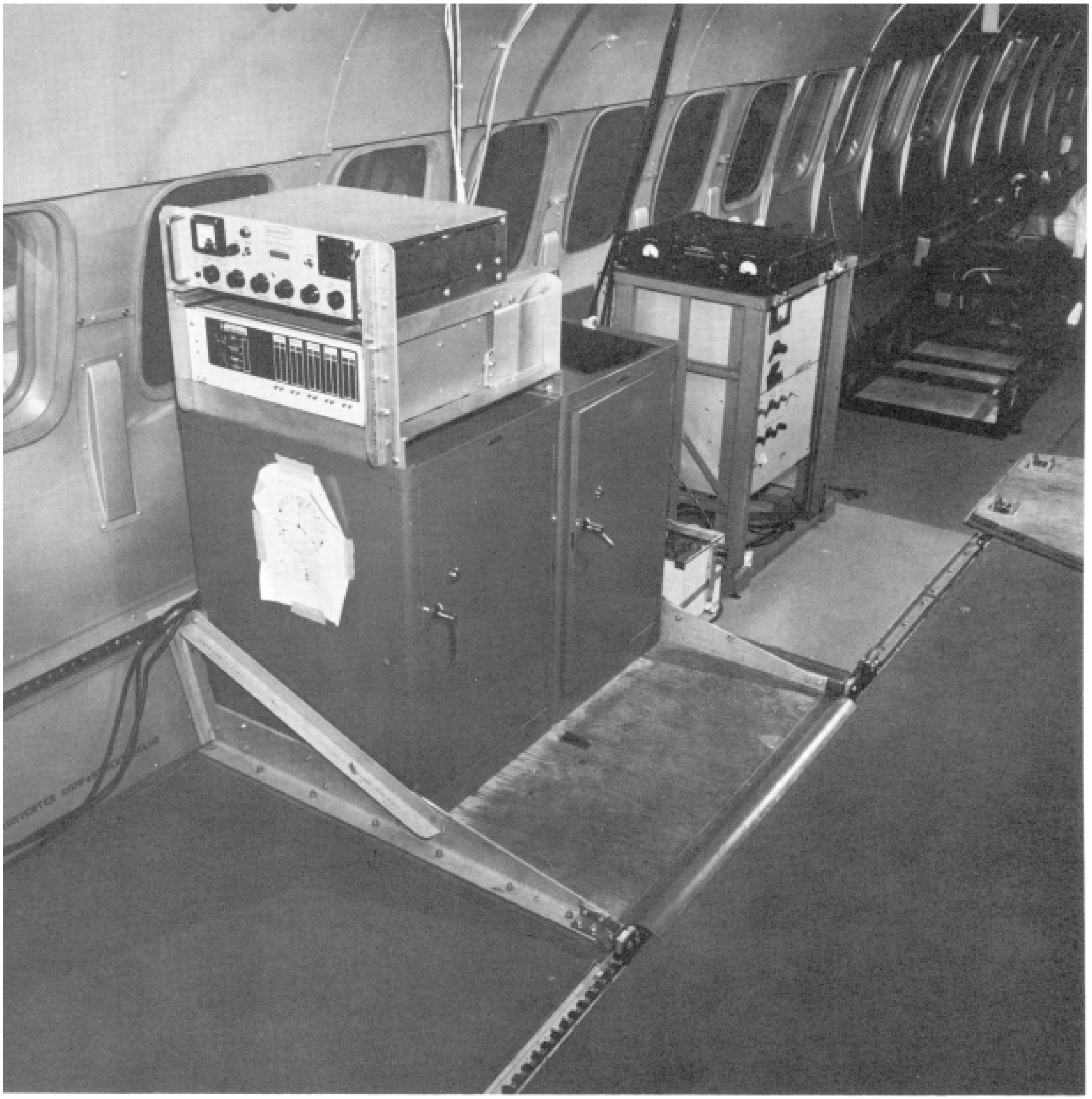
A-34471-153

Figure 17.- The coordinators’ console (see also figs. 2 and 4).



A-34471-154

Figure 18.- Typical electrical outlet and intercom system boxes serving two adjacent experimental stations. The small receptacle to the right of the dual electrical box is wired to the time code generator.



A-34471-75

Figure 19.- Time code generator, WWV receiver, and auxiliary dc power supplies.

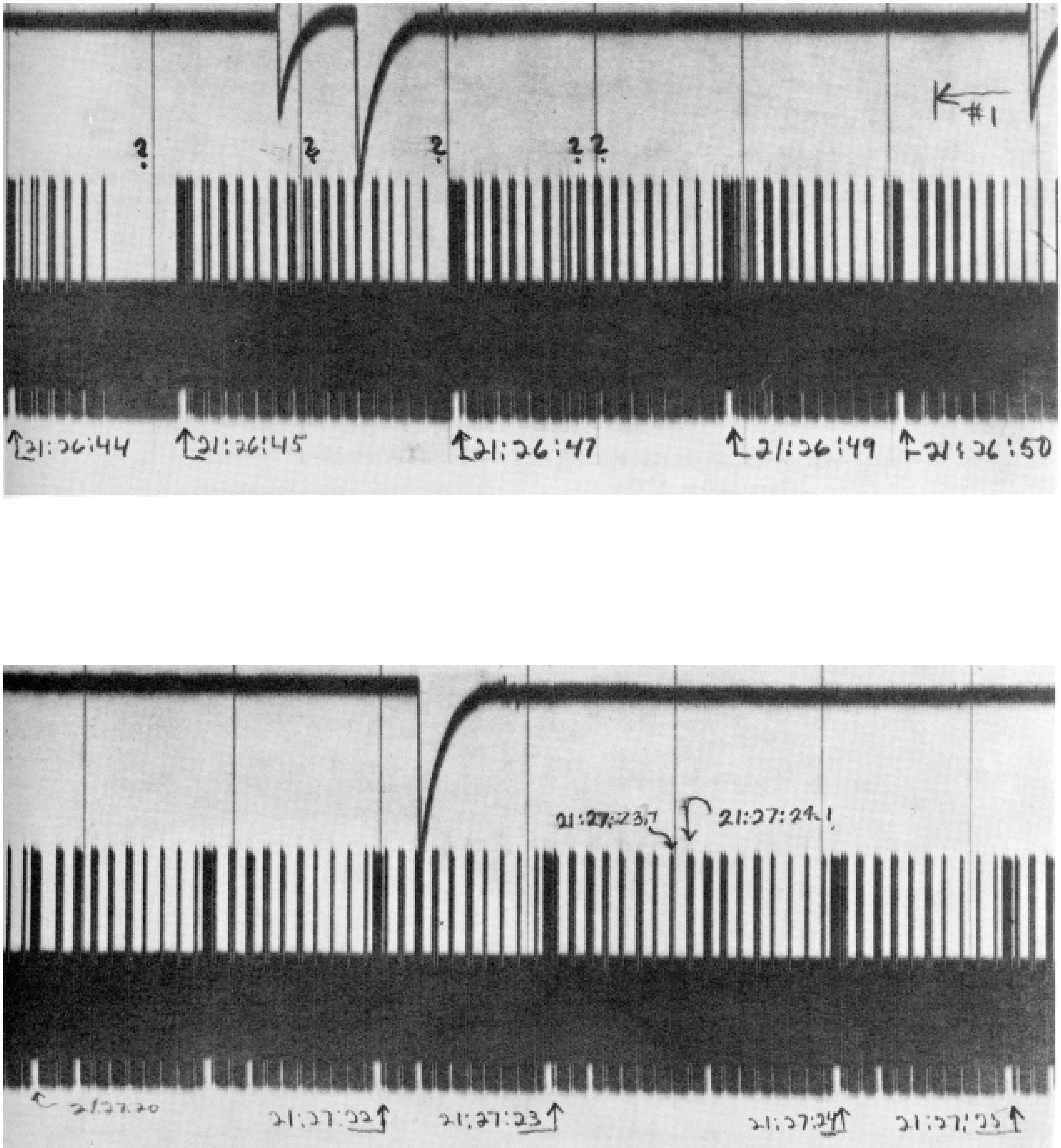


Figure 20.- Photographs of portions of a paper chart recording the time code generator BCD “level shift” output.

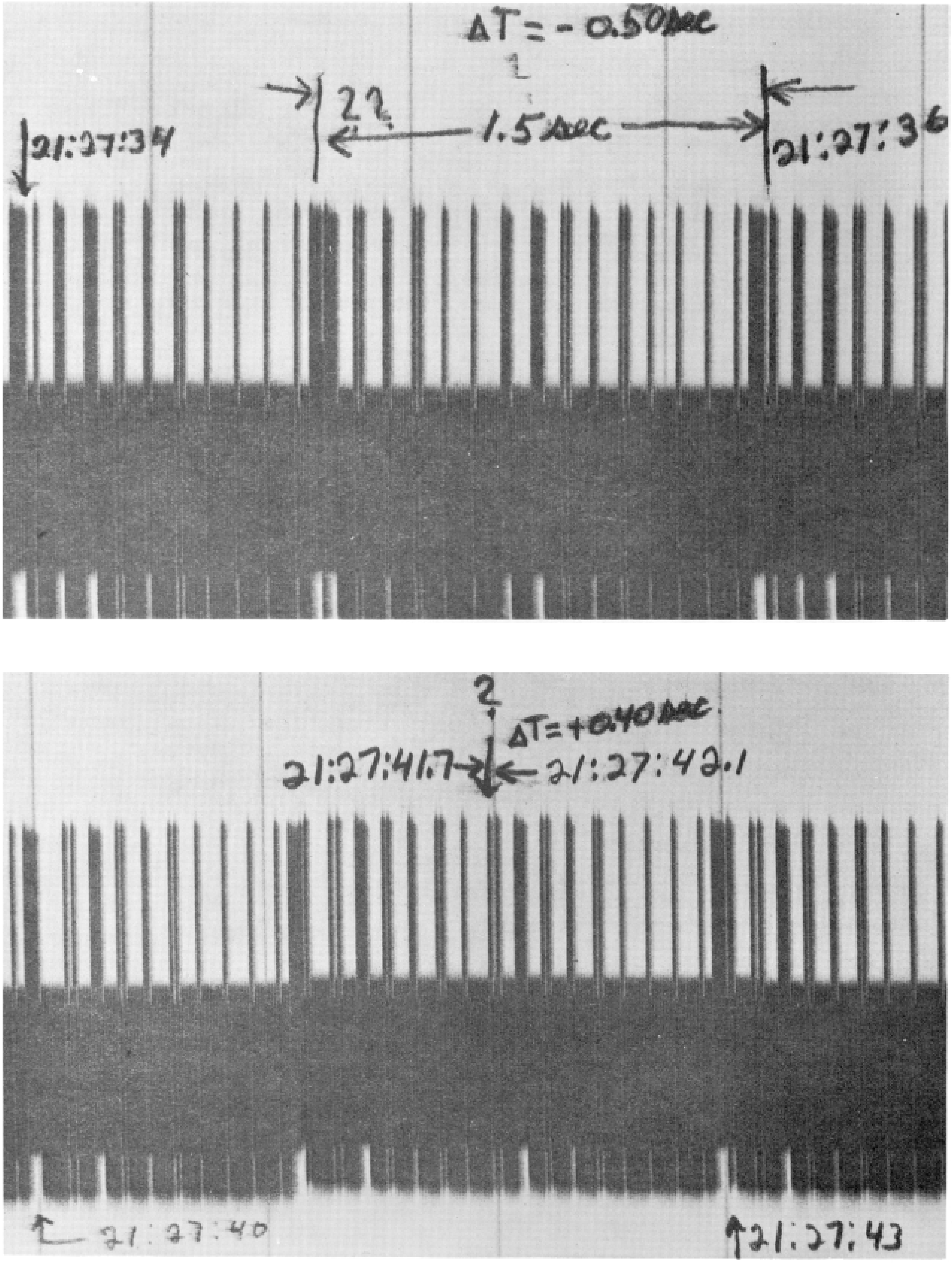


Figure 20.- Concluded.

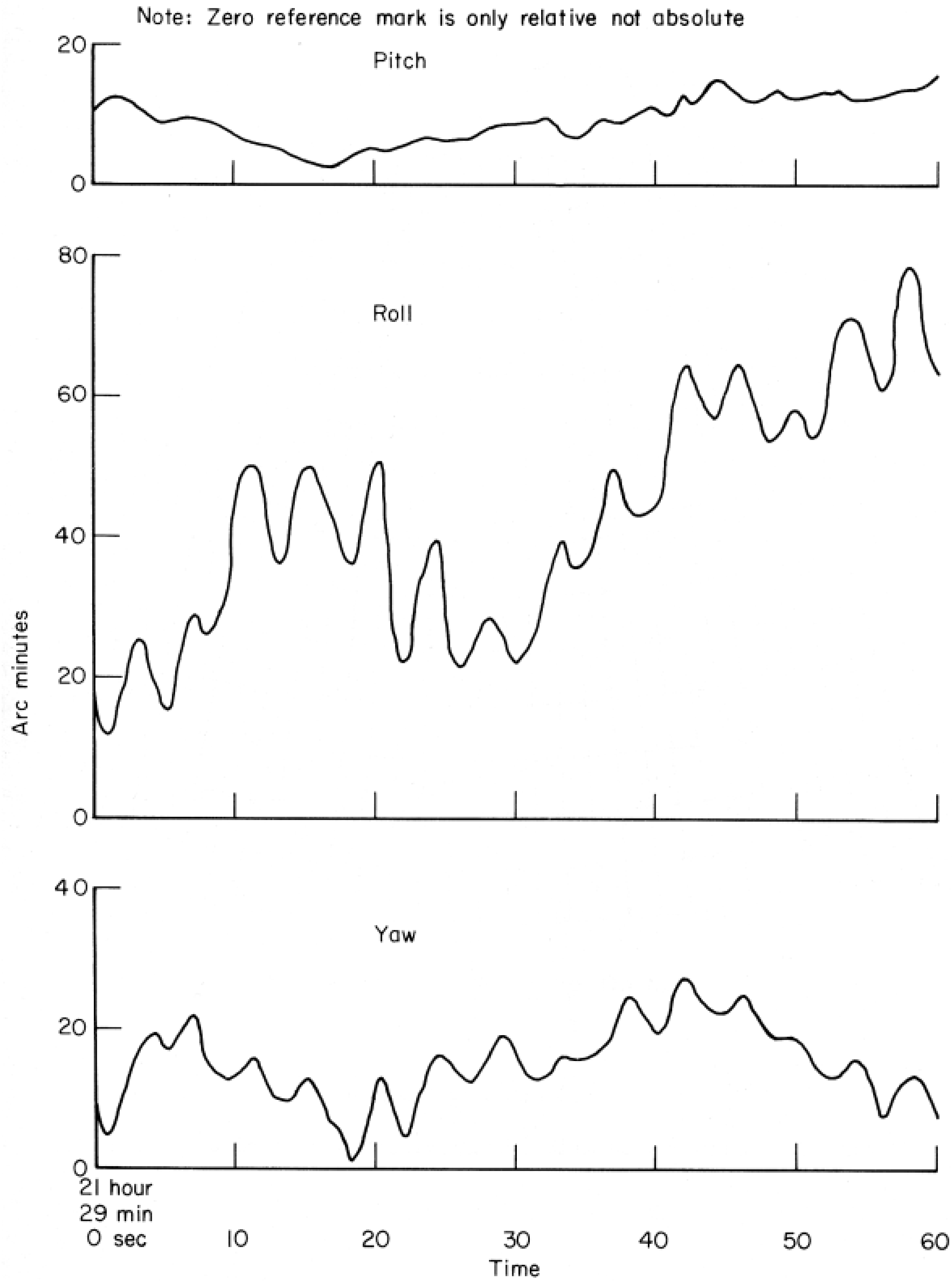
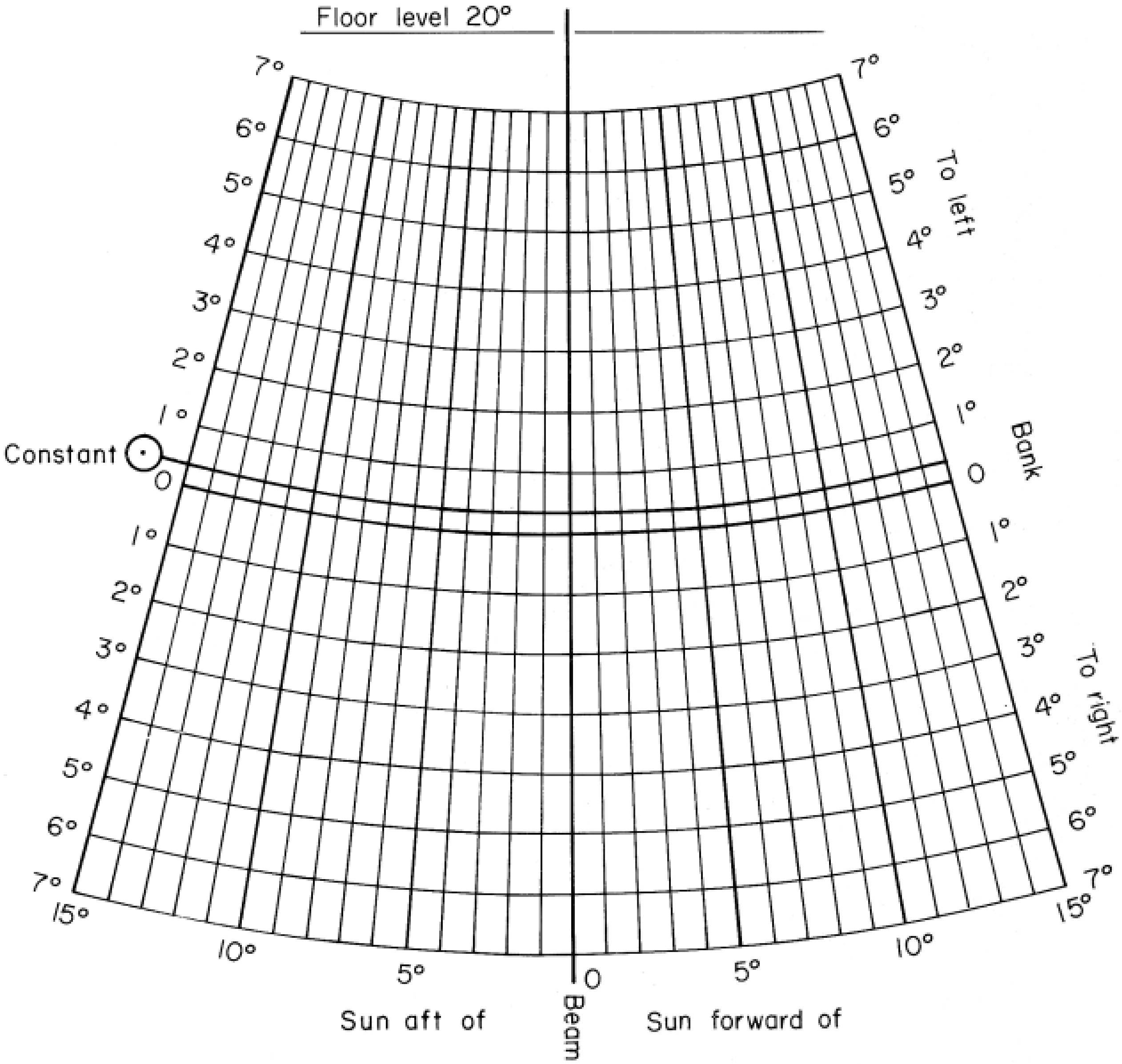
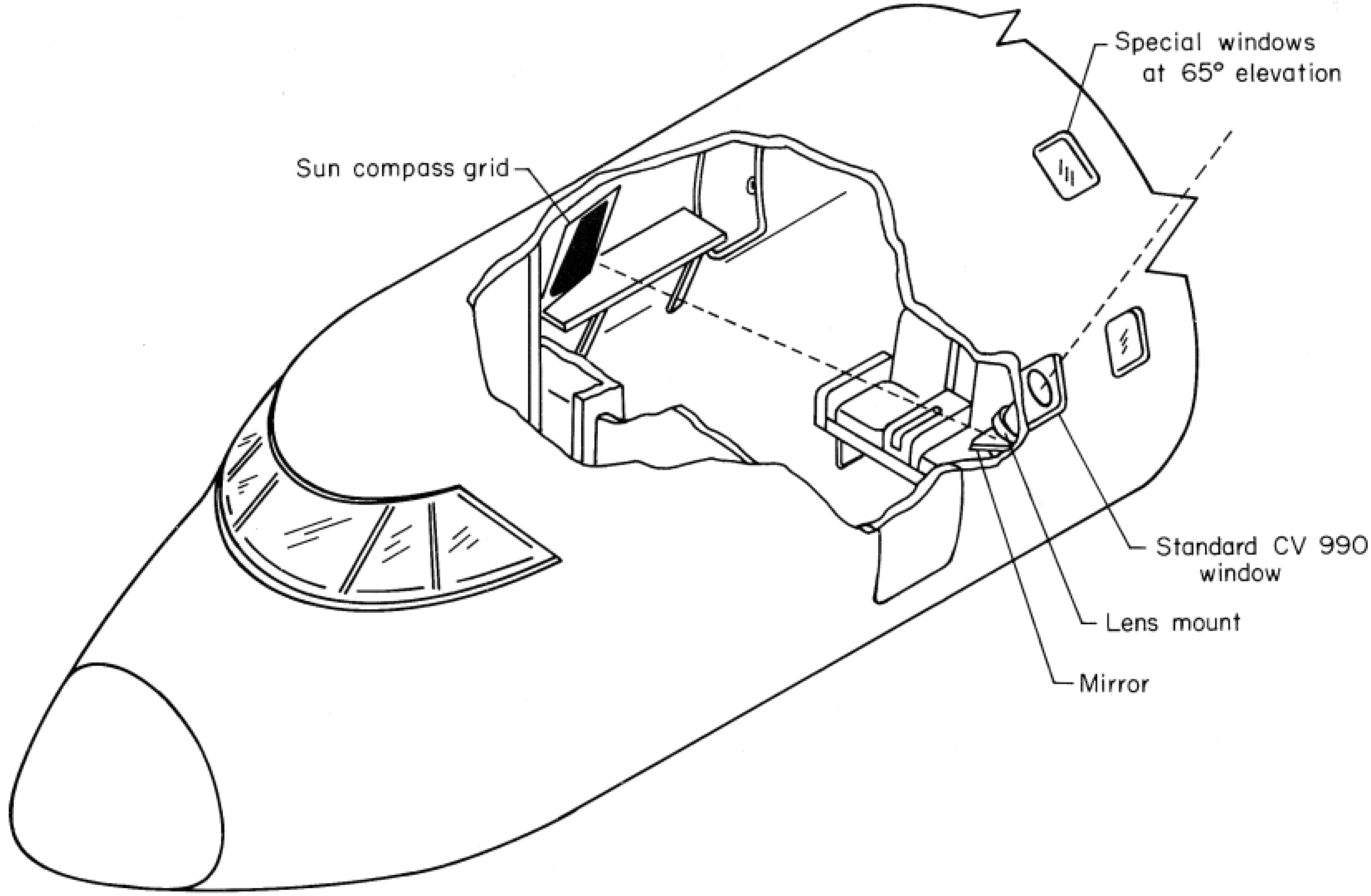


Figure 21.- Typical section of record of aircraft motion during totality.



(a) Sun compass grid.

Figure 22.- Sun compass grid and installation aboard the aircraft.



(b) Sun compass installation.

Figure 22.- Concluded.

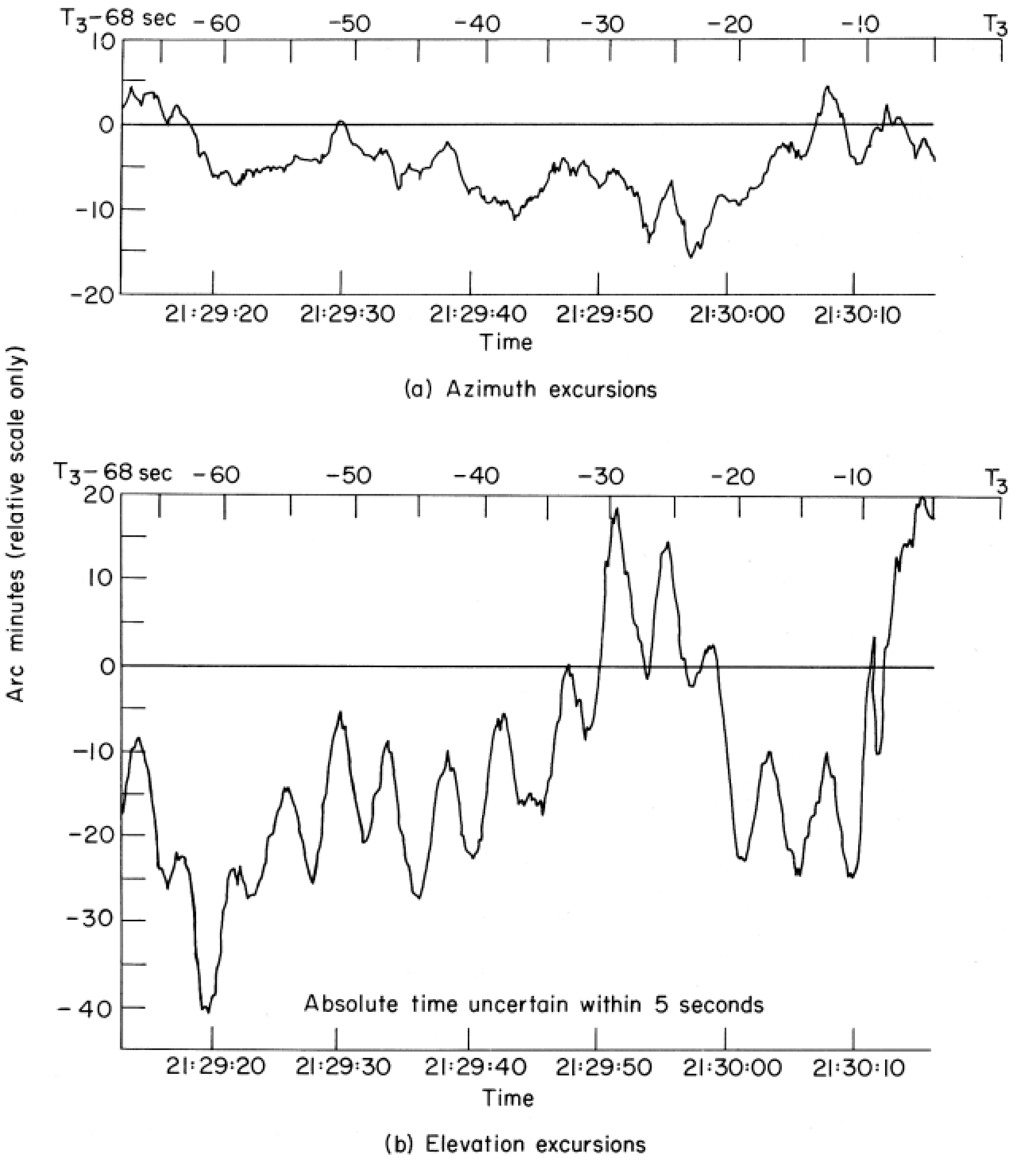


Figure 23.- Typical section of record of the sun’s azimuth and elevation excursions during totality.

NASA Langley, 1966 A-2269

"The aeronautical and space activities of the United States shall be conducted so as to contribute . . . to the expansion of human knowledge of phenomena in the atmosphere and space. The Administration shall provide for the widest practicable and appropriate dissemination of information concerning its activities and the results thereof."

-NATIONAL AERONAUTICS AND SPACE ACT OF 1958

NASA SCIENTIFIC AND TECHNICAL PUBLICATIONS

TECHNICAL REPORTS: Scientific and technical information considered important, complete, and a lasting contribution to existing knowledge.

TECHNICAL NOTES: Information less broad in scope but nevertheless of importance as a contribution to existing knowledge.

TECHNICAL MEMORANDUMS: Information receiving limited distribution because of preliminary data, security classification, or other reasons.

CONTRACTOR REPORTS: Technical information generated in connection with a NASA contract or grant and released under NASA auspices.

TECHNICAL TRANSLATIONS: Information published in a foreign language considered to merit NASA distribution in English.

TECHNICAL REPRINTS: Information derived from NASA activities and initially published in the form of journal articles.

SPECIAL PUBLICATIONS: Information derived from or of value to NASA activities but not necessarily reporting the results of individual NASA-programmed scientific efforts. Publications include conference proceedings, monographs, data compilations, handbooks, sourcebooks, and special bibliographies.

Details on the availability of these publications may be obtained from:

SCIENTIFIC AND TECHNICAL INFORMATION DIVISION

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Washington, D.C. 20546