NASA TM- 84229

NASA Technical Memorandum 84229

NASA-TM-84229 19820014604

A Portable, Low Cost Flight-Data Measurement and Recording System

Robert J. Miller

March 1982

NASA
National Aeronautics and
Space Administration

NASA Technical Memorandum 84229

A Portable, Low Cost Flight-Data Measurement and Recording System

Robert J. Miller, Ames Research Center, Moffett Field, California

National Aeronautics and
Space Administration

Ames Research Center
Moffett Field, California 94035

N82-22478 #

A PORTABLE, LOW-COST FLIGHT-DATA MEASUREMENT AND RECORDING SYSTEM

Robert J. Miller

Ames Research Center

SUMMARY

The report describes the design of and the experience with an inexpensive, hand-portable, onboard data system used to record four parameters in the final portion of the landing approach and touchdown of an airplane. The system utilized a high-quality audio tape recorder and amateur photographic equipment with accessory circuitry rather than specialized instrumentation to give satisfactory results.

INTRODUCTION

A study was conducted (ref. 1) that compared the performance on check rides of two groups of experienced airline pilots undergoing transition training. One group trained entirely on flight simulators and the other with a traditional mixture of simulator and aircraft time. Pilot performance was evaluated using three methods: (1) a check pilot's ratings, (2) a NASA observer's ratings and estimation of such measures as accuracy of Instrument Landing System tracking, and (3) an onboard instrument package which gave objective measures on the final portion of approach and touchdown, recording altitude, two components of acceleration, and touchdown location. For a later touchdown-modeling study (ref. 2, in preparation) recorded measures were altitude, pitch attitude, and vertical acceleration. This report describes the development of and experience with the compact, hand-portable system and its associated data-readout system.

METHODS

The study was conducted by researchers from NASA Ames Research Center with the cooperation of United Air Lines (U.A.L.). The check-ride subjects were Captains and First Officers transitioning to the Boeing 727 and Douglas DC-10. Flights originated at the U.A.L. Flight Training Center at Stapleton International Airport, Denver, Colorado, with landings at Stapleton or the Municipal Airports of Pueblo or Colorado Springs, Colorado. Touchdown-modeling flights originated at San Francisco International Airport with landings at Sacramento, Oakland, or San Francisco. The aircraft used were made available between revenue flights, so specific aircraft to be used could not be identified nor specially prepared beforehand. This also resulted in the majority of the flights being scheduled in the midnight-to-4 a.m. time-frame. Aboard the aircraft, in addition to the trainee, check pilot, and crew, there was a NASA observer, a retired U.A.L. Captain, who occupied the jump seat behind the Captain with a view of the instrument panel. He recorded several measures of pilot performance and controlled the instrument package located in the cabin at the center of gravity of the aircraft.

The instrument package was developed at Ames Research Center and, for the main body of the study, was to meet the following criteria:

1. The system was to record, for at least the last 200 ft of the descent to landing, the lateral and vertical accelerations ($\ddot{y}$ and $\ddot{z}$) and altitude (z). Accelerometers were to be a part of the package and altitude was to be obtained from the radio altimeter system of the aircraft. Touchdown point along the runway was to be recorded.

2. The entire system was to be portable, readily carried by one man and, except for the connection to the radio altimeter, installable by the observer in 20 min or less.

3. It was to be independent of aircraft power.

4. It was to provide for the subject of each data block to be identified and for the touchdown event to be marked by the observer.

5. Time and cost constraints required the use of equipment available in-house.

A block diagram of the system is shown in figure 1. Analog recording techniques were chosen as the most readily realizable with the resources available.

FLIGHTPATH DATA SYSTEM

A compact, battery-powered, high-quality tape recorder was available. This was a Nagra-Kudelski model IV-SJ, used widely in acoustics work. It weighed 70 N (16 lb) and had three recording channels, two direct with 25 Hz to 20 kHz frequency response and one with internal frequency modulation and demodulation providing a frequency response from DC to 4 kHz. This FM channel, customarily used for commentary or synchronization, had a fixed gain with a linear range of ±3 V and required a -1 V bias to record. With the cover closed, it accepted a 12.5-cm (5-in.) reel of tape giving 22 min of recording time at 19 cm/sec (7.5 in./sec). Connection for a remote on-off switch was provided.

The altitude signal was supplied by the radio altimeter system of the aircraft. The pilot's display was disconnected and a short jumper cable interposed to pick off an auxiliary DC altitude signal for transmission to the recording system. Since this installation affected flight safety, precautions were taken to assure that instrument performance was not affected: The entire package was isolated from ground except at this point to avoid ground loops, the input impedance was kept at 50 kΩ to minimize loading effects, FAA and UAL design approval was obtained, and a UAL mechanic installed and removed the jumper from the aircraft for each flight.

Lateral acceleration was measured by a four-active-leg unbonded strain-gauge accelerometer mounted on the instrument package.

The direct channels of the recorder were used for $\ddot{z}$ and $\ddot{y}$. Since DC response was required, data were stored in frequency-modulated form, the inputs being used to modulate carrier frequency generators based on type LM566 integrated circuits, with circuit design concepts discussed in reference 3. Carrier frequencies near 10 kHz were used, with deviations of about -2 kHz at the nominal range of interest of the altitude and pitch attitude values, 200 ft and +15 deg and ±2 kHz/G lateral acceleration.

Vertical accelerations were measured by a force-balancing servo-type accelerometer with output of 3.8 V/G. The signal was biased and attenuated before recording on the third, or FM, channel of the recorder.

A cable ran from the instrument package forward to the observer's station in the jump seat behind the Captain, connecting at that point to the altimeter jumper. The observer was provided with a controller grip with a run/standby switch and a pair of push-button switches to allow identification coding and event marking. These controlled circuitry in the modulator that switched the input from the y-axis accelerometer to a fixed offset level. For coding, the offset was applied as long as the switch was depressed, allowing subject number and other data to be applied in Morse code. For the touchdown mark, since y-acceleration data were obscured by the marking offset, it was necessary to insert a delay of 5 sec before the fixed 0.3-sec mark was applied. Then, during analysis, the calibrated delay was subtracted to calculate the observer's estimate of touchdown time. The timer circuit was based on an integrated-circuit type XR-2240 programmable counter-timer, that allowed the use of low-temperature coefficient timing resistor and capacitor of readily available small values. Circuitry used was based on material in reference 4.

The accelerometer-recorder package is shown in figure 2. A base plate of 64.7 by 31.8 cm (25.5 by 12.5 in.) was secured to the floor of the aircraft near the nominal center of gravity. In the DC-10, this is in a row of centerline seats, so the separate clamps in the foreground were used to engage the seat tracks. In a B-727, this is in the aisle, so the post structures at the sides engaged the under-seat parcel retainer bars. The accelerometers were mounted at the back right corner of the plate and the mercury batteries powering the modulator were at the back and the left edges of the plate. The recorder and modulator were mounted on a second plate which was electrically and vibration-isolated from the base plate. The entire package weighed 140 N (32 lb). At the right of the package in figure 2 is a portion of the cable to the observer's position showing the controller grip and the pigtail that connects to the altimeter jumper cable. Cable weights were 31 N (7 lb) for the DC-10 and 27 N (6 lb) for the shorter B-727.

The components of the system proved awkward for the move from the UAL Flight Training Center to the aircraft at a terminal gate, so the backpack shown in figure 3 was built for the recorder package. Strap attachment points were patterned on a camper's backpack. The bottom yoke provided a stable base for standing the pack while loading the recorder package or putting it on, as well as providing attachment points for the hip strap that spaced the frame away from the lower back and allowed it to be held lightly forward onto the shoulders by the shoulder straps. Bungee cord around the B-727 posts held the package down into the clips at the base.

In a follow-on study, validation of a model of touchdown flare performance was attempted and the instrumentation was modified to fit the new requirements of the task. In this phase, pitch attitude replaced y-axis acceleration. Touchdown point measurement was not required and aircraft electric power was available, provided ground isolation (except at the radio altimeter) was maintained.

Pitch attitude information was provided by a vertical-axis gyroscope originally used in a bombing computer system. Two degrees of freedom were available but the roll output was not used. The unit was electrically operated, with spin and erecting motors operated by 400 Hz single-phase power at 115 V and 28 V, respectively. Potentiometer attitude pickoffs were supplied ±15 V DC, and uncaging was accomplished by 28 V DC. Uncaging was found to apply unpredictable upsetting impulses to the gimbals, so a 90-sec delay was imposed to allow for spinup and avoid any risk of upsetting beyond erecting-motor limits. A further modification to the power supply for the erecting motors was necessitated by their fundamental design: They slowly align the spin axis of the gyroscope with the gravity vector. In normal flight, this causes no problem since longitudinal and lateral accelerations sufficient to displace from vertical the apparent gravity vector (actually, the resultant of gravity plus acceleration vectors) are of short period; the slow erecting motors do not respond. After touchdown, however, the aircraft decelerated under the sum of reverse thrust, braking, and drag at 0.3 to 0.4 G, and the erecting motor responded by pitching the gyroscope at about 0.1 deg/sec. This resulted in a loss of zero-pitch-angle reference and in data that had to be considered invalid after touchdown. To resolve the problem the record/standby switch was wired to turn off erecting motor power during recording. Drift during a typical recording period of 1 to 2 min was found to be negligible.

The block diagram of the system as modified for this phase is shown in figure 4, with a photo to the completed system in figure 5. The recorder package was modified from the original configuration by removal of lateral accelerometer, batteries, and B-727 retainer posts, to make room for power supplies on the base plate. The gyroscope was mounted on a separate plate 33.0 cm by 31.8 cm (13.0 by 12.5 in.), with the associated power and control functions, as indicated by the dashed lines dividing subassemblies in the block diagram. The gyro subassembly weighed 57 N (13 lb) and was clamped to the seat tracks one row ahead of the recorder package in the same fashion as the recorder package. The 115 V 400 Hz electric power was drawn from a convenience outlet in the aircraft cabin wall.

CALIBRATION AND DATA EXTRACTION

Since data collection was remote from the reduction process, it was necessary that the calibration scheme be insensitive to system variations (battery voltage or component drift, speed difference between recorders, etc.) and desirable that calibration signals be permanently applied to each data tape. Consequently, a two-stage process was adopted. In the lab, transducers were checked for linearity, hysteresis, and similar factors, and a set of resistor networks were adjusted to simulate each transducer's output at a pair of values representing the estimated limits of its input values. Then, before each flight, the resistor networks were substituted for the transducers and the two values were recorded on the tape, to be read later during data reduction at NASA Ames to establish the scale for the data of that flight. Accelerometer calibration values were established by tilting the package so that a component of the earth's gravity acting on the uniaxial accelerometers was of the desired level, +0.5 G and -0.5 G for the lateral ($\ddot{y}$) and +1.00 G and +0.707 G for the vertical ($\ddot{z}$) accelerometers. (It is recognized that a larger and symmetrical pair of values in $\ddot{z}$ would have been desirable, but the values were chosen to be rechecked without use of a shaker table at Denver where the package remained for the duration of the original study.) Calibrating values for the gyro were 0 and +15 deg (nose up). In the case of the altimeter, the transducer was a component of the aircraft and was not available to NASA personnel, so nominal values of output at 200 ft and ground level were used. In this case, an accuracy check was provided during the touchdown modeling phase by a comparison with the barometric altimeter. The observer marked the times of passage through hundred-foot multiples using the code button on the controller grip, and these baro-altimeter values were compared with the demodulated radio altimeter data. Scatter was of the order of ±10 ft, less than the baro-altimeter's 20-ft minor graduations. The radio altimeter (hence glide slope gradients and descent rates) was consistent among aircraft and 4 - 5% low. This was thought to have been the effect of electrical loading on the auxiliary signal source despite the high input resistance.

Data tapes, along with observer's and check-pilot's scoring forms and touchdown point films, were returned to Ames Research Center for processing. The two direct-record channels, carrying altitude and $\ddot{y}$ or pitch attitude data, were played into a pair of phase-locked loop demodulator circuits. These were built in-house and based on the LM 565 integrated circuit with circuitry described in reference 3. The vertical accelerometer ($\ddot{z}$) data were demodulated within the recorder. All channels were provided with buffer amplifiers with biasing and scaling capability to maintain the signals within the ±1.0-V range of the analog-to-digital converters of the digital computer to which they were connected. The data reduction process is described in reference 5.

TOUCHDOWN LOCATION MEASUREMENT

Touchdown location, in terms of distance from runway threshold, was recorded by a camera onboard the aircraft. This camera faced out a cabin window toward distance markers placed at about 61 m (200 ft) intervals (depending on the airport and runway) on the runway-edge light mounts. The location of the aircraft with respect to a visible marker was then determined by measuring the image location on the film and applying the method of similar triangles, using the distance from the runway edge and the focal length of the lens as the known quantities. In practice, an overlay was prepared for each aircraft type and runway (because of different widths) and the number read directly, rather than calculating each case. This method is sensitive to both yaw at touchdown and lateral distance from centerline. Thus, at the beginning of the program an observer set up a remote-control camera on the extension of the runway centerline of Stapleton airport and photographed the touchdowns of all air carrier flights for one working day: No touchdown errors were observed that would introduce significant errors in touchdown-point measure within the 3-m (10-ft) resolution of that measure. While this was done under ideal daylight flying conditions, it was assumed to be applicable throughout the program.

A camera installation is shown in figure 6. Note the power winder at the base of the camera and the rotary solenoid and cam to actuate the shutter release when operrated by the touchdown marker button on the observer's controller grip. The mount fits the cabin window shade track and is installed and removed by being raised and rotated clockwise as seen in this view. The lap belt of an adjoining seat secures it by passing through a safety strap, not shown in this photo. Solenoid batteries are inside the mount, so it requires only closure of the touchdown switch to operate. With the switch held down, the power winder was found to sequence the camera consistently at 0.56 ±0.01 sec.

The camera was standard 35-mm format with a lens of 28-mm focal length, giving a coverage of about 38 m (125 ft) at the lights on the 61-m- (20-ft-) wide runway 27 L at Denver. On the 46-m- (150-ft-) wide runways at Pueblo and Colorado Springs, coverage was about 29 m (95 ft). Since this was less than the marker spacing, a photo at touchdown might not include a marker. Therefore, the touchdown switch was held for 3 - 4 sec, which assured that at least two frames would include markers. From these two locations, the constant frame rate allowed extrapolating back to touchdown, assuming constant aircraft speed.

For daytime flights, black-and-white film of ASA 125 speed was used and the camera set for 1/1000 sec with aperture set automatically. Motion blur was of the order of 6 cm (2.5 in.), but a horizontally elongated style of numerals was devised that was readable despite blurring (fig. 7). The distinctive placement of horizontals also made them more readable near the limits of resolution. For night operations, the film used was of ASA 400 speed, with processing for a speed of 800. An electronic flash unit on a similar mount was installed in a cabin window adjoining the camera. The distance to the runway edge was too great for a lightweight portable flash to light the markers if used conventionally, but 2.5-cm- (1-in.-) wide, white retroreflective tape ("Scotchlite") was applied to the black-painted plates to form the numbers and provided generous exposure. The necessity for repetitive flashes at 0.56 sec was met by: (1) Selecting a flash unit having provision for direct recharging of the storage capacitor from a high-voltage (510 V) battery instead of the usual inverter supply with low-voltage batteries and, (2) having a thyristor turn-off of the flash discharge that can be controlled by a manual setting as well as the usual auto-exposure photo-cell. The flash output was set to produce a minimum exposure of the retroreflective tape, at about 25% of the maximum output of 1900 beam-candlepower-seconds. This decreased effective flash duration to 0.6 millisec, further reducing motion blur, eliminated overexposure "blooming" of the image, and reduced energy drain from the flash capacitor to a value that could be nearly recovered in 0.56 sec. (Energy stored was not entirely recovered, so exposure decreased noticeably but not excessively for the five or six pictures that were the maximum used.) The camera and flash installations each weighed about 27 N (6 lb).

The major criteria imposed on the marker plates were (1) sufficient strengh to resist being carried away by the very high air loads imposed by vortices shed from the wing tips of the heavy aircraft passing just over them as they flared for landing, and yet (2) to be frangible enough to do no damage if run over or hit. They were made from polycarbonate plastic, heated and bent into an L-shape and bolted to the runway light mounting bases at ground level.

RESULTING DATA

Analog Data

Figure 8 shows examples of some flight data as reproduced on the strip-chart recorder. Seen from top to bottom are the altitude, z-axis and y-axis accelerations, and a time trace showing a deflection each second, added by the strip-chart recorder. At left, the record begins with calibration steps followed by the Morse code characters for subject number "429" and the location for the first landing "DEN," on the y-axis accelerometer trace. The large and simultaneous pen excursions that separate segments of record are recorder stop/start transients. Next, to the right, a 54-sec segment shows the first landing of subject 429, which was very smooth and very highly graded by the observer. This is indicated by the smooth and well-timed flare seen on the altimeter record and the smooth onset of accelerations. The touchdown mark on the y-accelerometer trace is visible near the end of the segment, appearing as a 0.3-sec deflection identical to the earlier coding marks. Counting back 5 sec locates the point where the observer judged touchdown to occur.

During the first 20 sec, the altimeter trace has reverted to a bias setting rather than correctly demodulating the input signal: This is characteristic of a phase-lock loop demodulator circuit with its input signal outside its range. It occurred here because the recorder was turned on at too great an altitude, about 600 ft. At about 300 ft, the signal moved into capture range and the circuit locked on.

A record of a distinctly rougher landing by another pilot is shown to the right of that of subject 429. A minimal flare, a vertical velocity of about 12 ft/sec at touchdown, and a vertical acceleration pulse of about 0.5 g for 0.5 sec are readily visible. This time, the touchdown marker failed to reset and delivered eight pulses, but the leading edge of the first was used and the others disregarded.

In the study report in reference 1 it was noted that some data were lost to instrument system failures, with explanation deferred to this report. Losses early in the program were due to quality assurance defects: Components worked out of sockets as the system was handled, a connector pin dislocated, and a wire broke at a connector. A series of runs late in the program was lost to an atypical battery failure. For a mercury battery, the expected curve of voltage with service shows an output constant within 5% over 90% of its life, with essentially no polarization effect (i.e., short term drop that is recoverable after a "resting" period). While the frequency modulation circuitry was sensitive to supply voltage, the procedure of calibrating at the beginning of each flight made the variation negligible within each 2 - 3 hr flight. One battery, however, appeared to deplete like a carbon-zinc type, with a reversible decrease of about 7% over an hour of operation, and this caused an excessive sensitivity and frequency shift. Ultimately, as in the example of figure 8, the demodulator had difficulty locking on to the signal. As flights were analyzed in batches, several were affected before the problem was detected. The atypical behavior was never understood.

Photographic Data

The photographic touchdown-point measuring system worked satisfactorily, initially, although the numerous 32- × 40-cm (8- × 10-in.) enlargements that were needed proved to be a significant cost, and manually locating and reading markers took more man-hours than expected. However, two significant oversights finally manifested themselves, traps set by developing the system under circumstances very different from those under which it was used. It snows in Colorado. The ground-level marker plates were buried or plowed under. Later, a number of flights were delayed from their expected midnight schedules until they included dawn twilight. These included a light condition too low for daylight shutter speeds of 1/1000 sec, but so great that there was overexposure and motion blur at the night settings of f/2 and 1/60 sec (due to the operating sequence of the focal plane shutter used on this camera, the fastest setting usable with electronic flash units). In view of these problems and the high cost of the photographic analysis, the estimation of touchdown location by the NASA observer was studied and found to correlate quite well with successful photo results ($r = 0.90$, where $1 - r^2$ is an index of the rms scatter of points around a line of slope = 1 on a plot of observer's estimate vs. photographic measure). This was then used for later phases of the study.

CONCLUSIONS

The requirements for an effective, portable, self-contained instrumentation package were met by the system described. Economies were realized by adapting available audio tape recorders and moderately priced photo equipment with simple control and signal-conditioning equipment rather than using specialized instrumentation equipment.

REFERENCES

1. Randle, Robert J.; Tanner, Trieve A.; Hamerman, Joy A.; and Showalter, Thomas H.: The Use of Total Simulator Training in Transitioning Air-Carrier Pilots: A Field Evaluation. NASA TM-81250, 1981.

2. Haffley, Robert K.; Schulman, Ted M.; Randle, Robert J., Jr.; and Clement, Warren F.: An Analysis of Airline Landing Data Based on Flight and Training Simulator Measurements. Systems Technology Inc., TR 1172-1, 1981.

3. Signetics Corp.: Signetics Analog Data Manual. Sunnyvale, CA, Aug. 1977.

4. Exar Integrated Systems, Inc.: XR-2240 Programmable Timer/Counter. Sunnyvale, CA, 2nd Rev., Nov. 1977.

5. Lee, Edward: NASA/UAL TSTS Data Processing. Informatics, Inc., TN-79-2001-205-5, June 21, 1979.

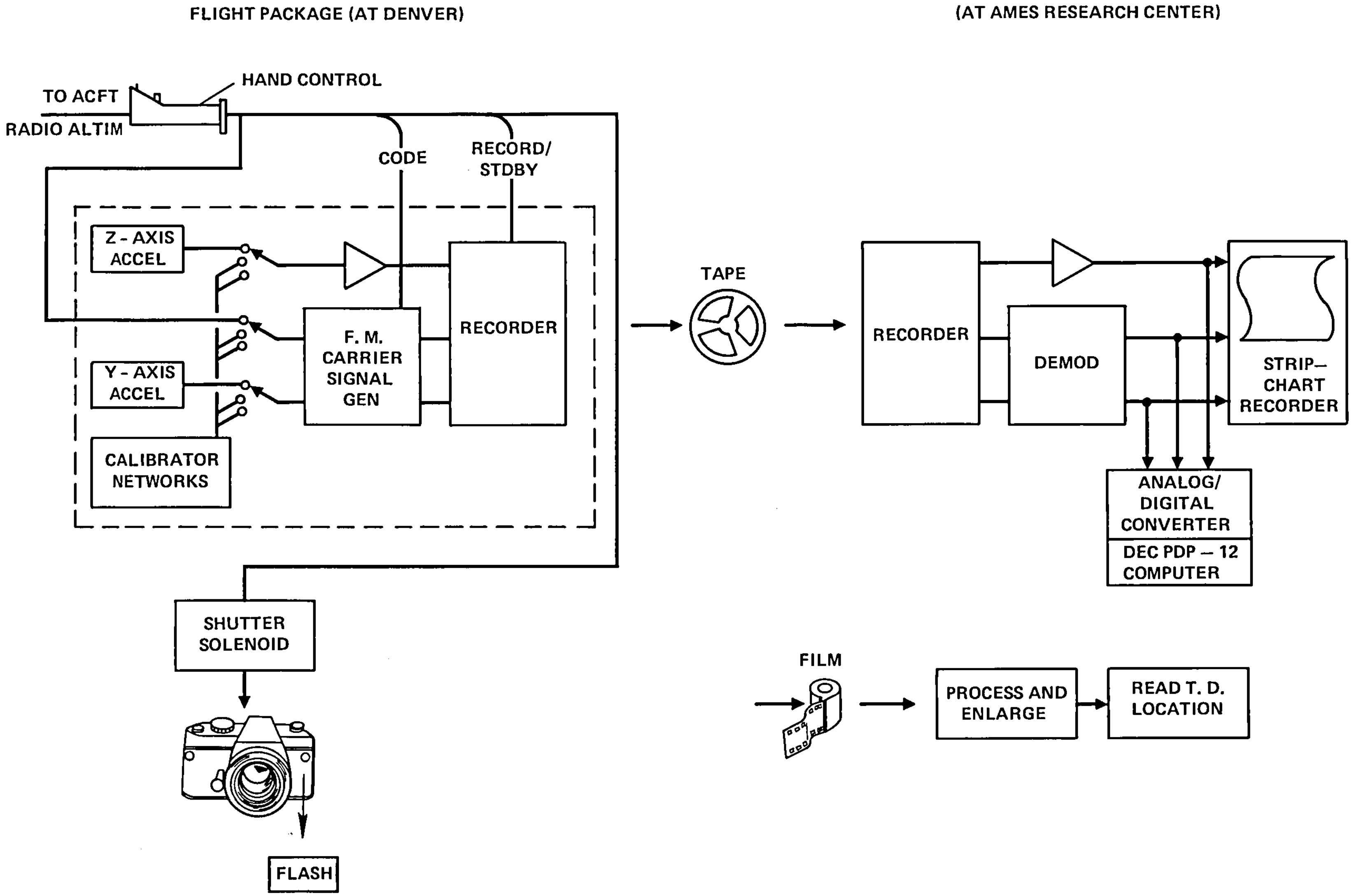

Figure 1.- Flight data system block diagram.

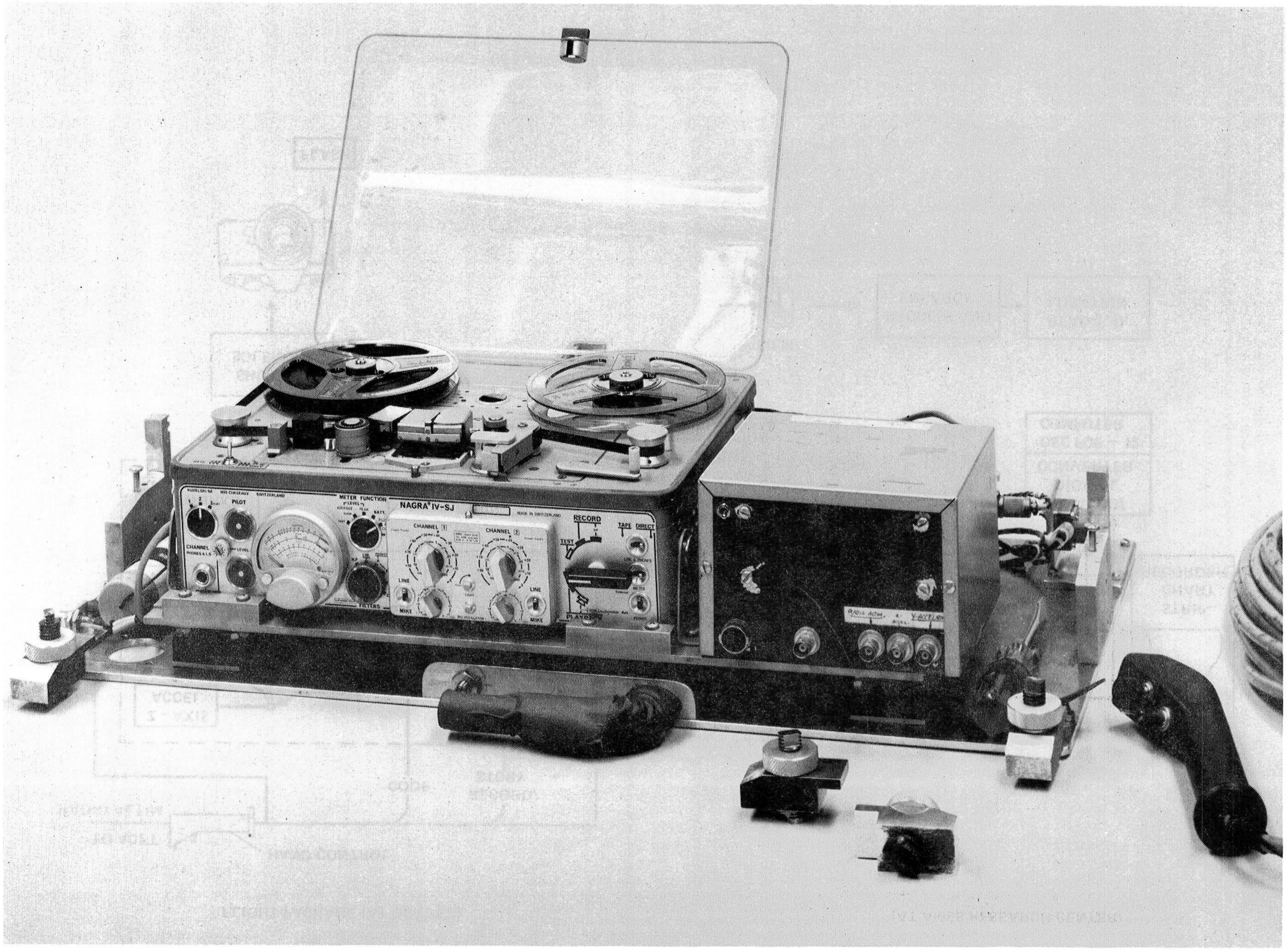

Figure 2.- Accelerometer-recorder package.

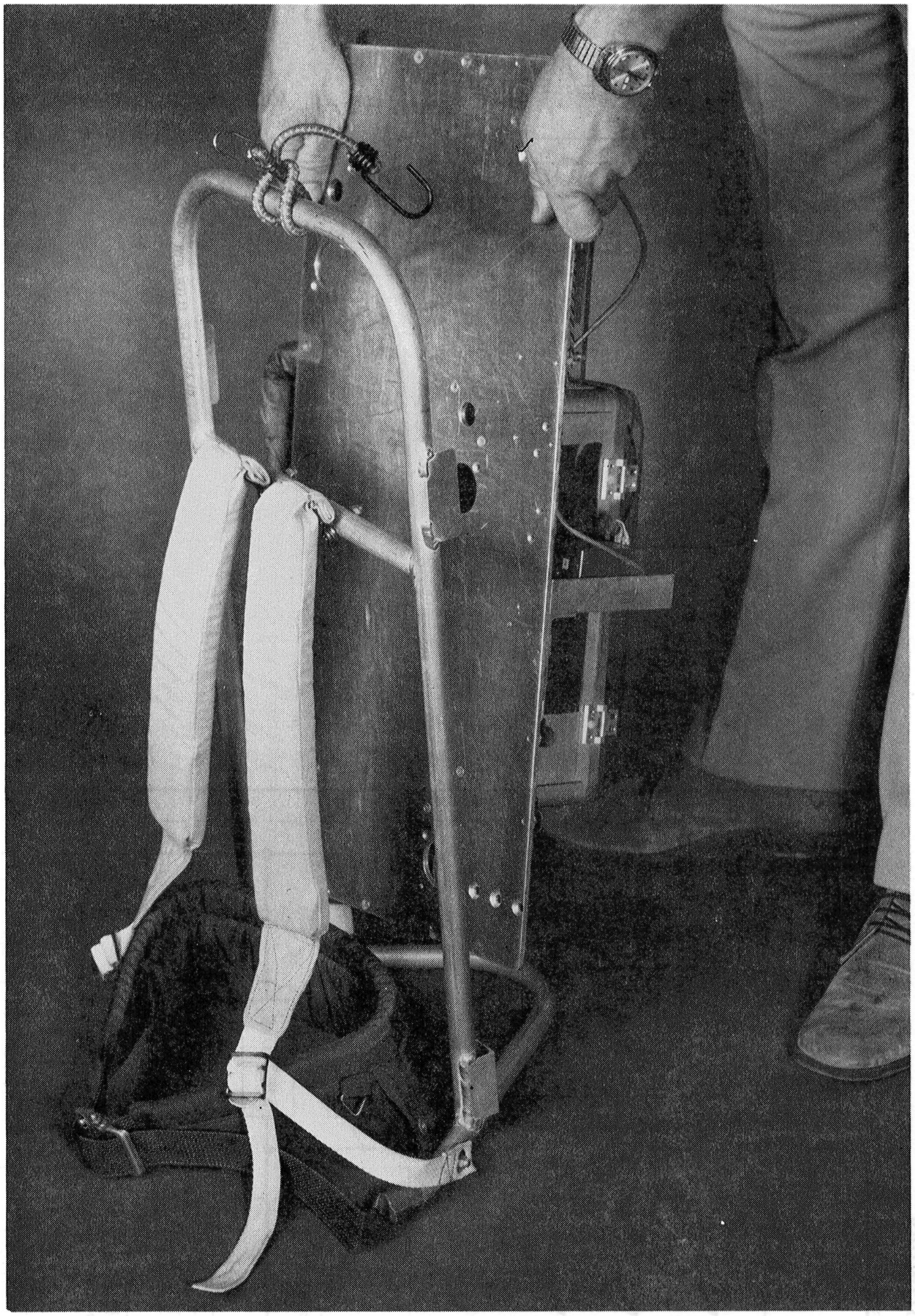

Figure 3.- Backpack.

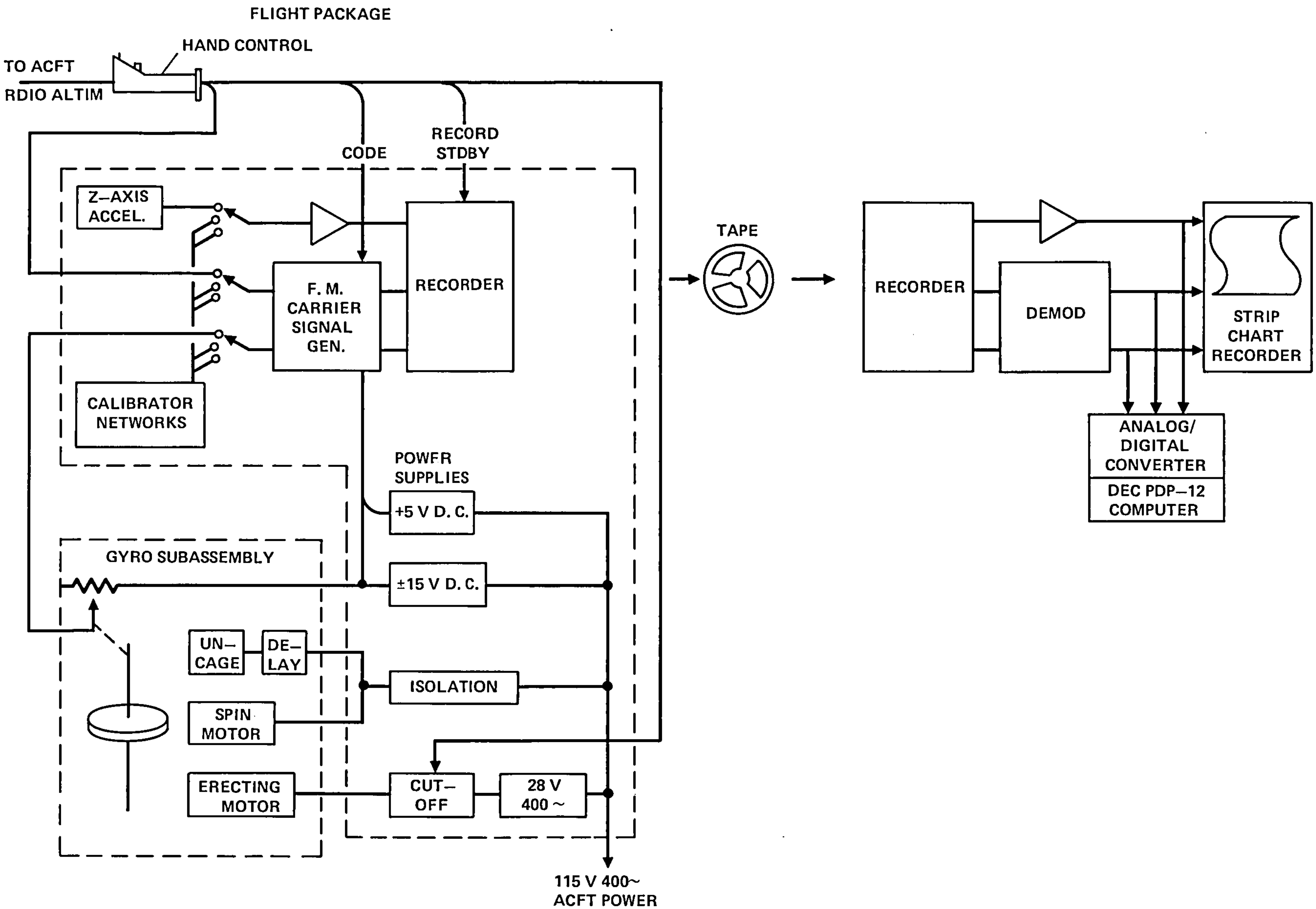

Figure 4.- Touchdown-modeling phase system block diagram.

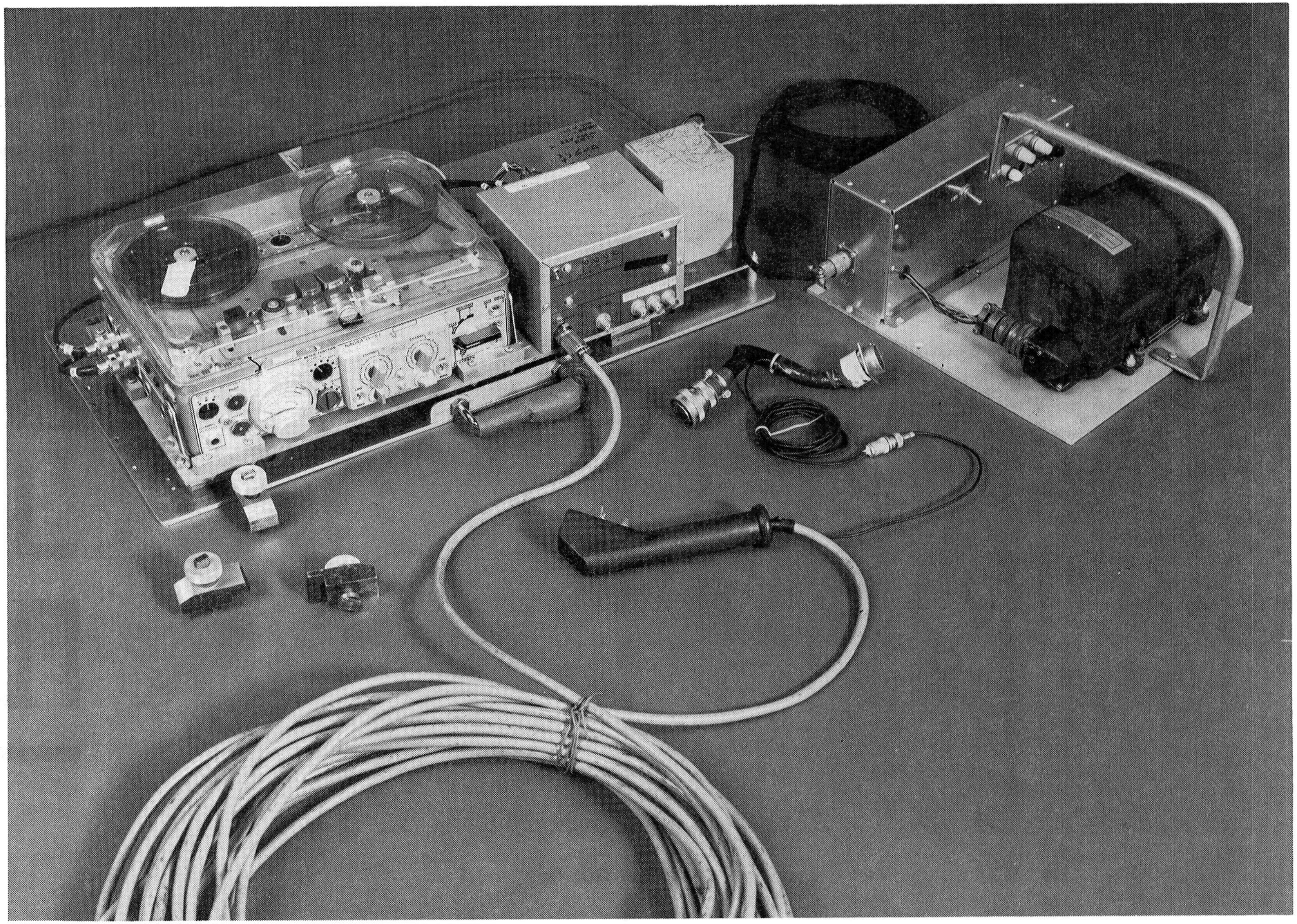

Figure 5.- Touchdown-modeling phase flightpath data system.

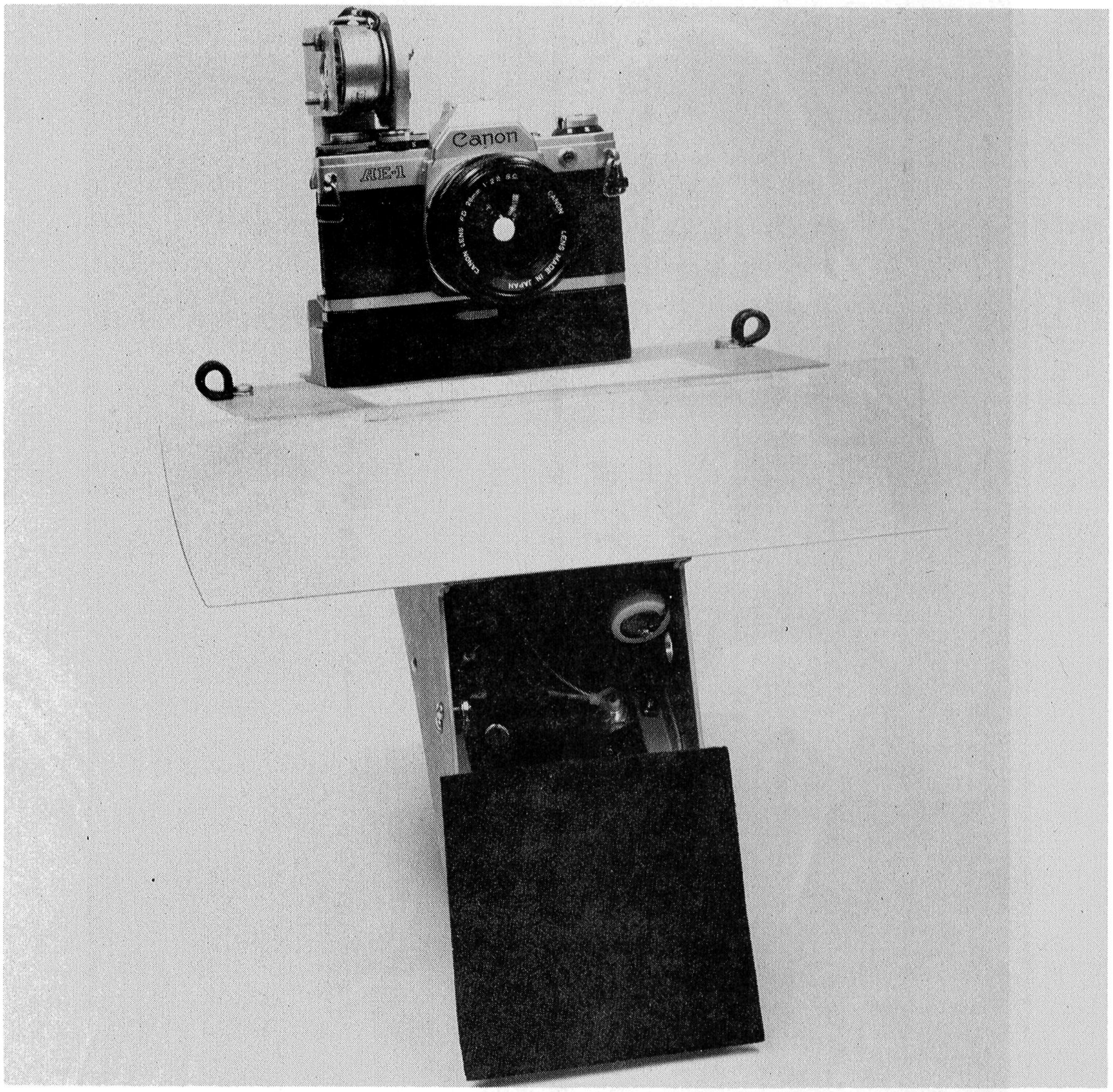

Figure 6.- Camera on mount.

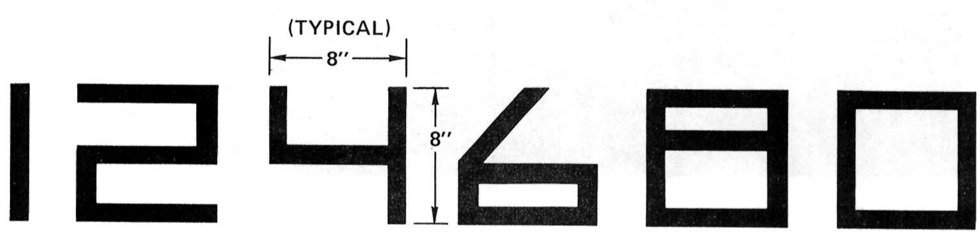

Figure 7.- Numeral style.

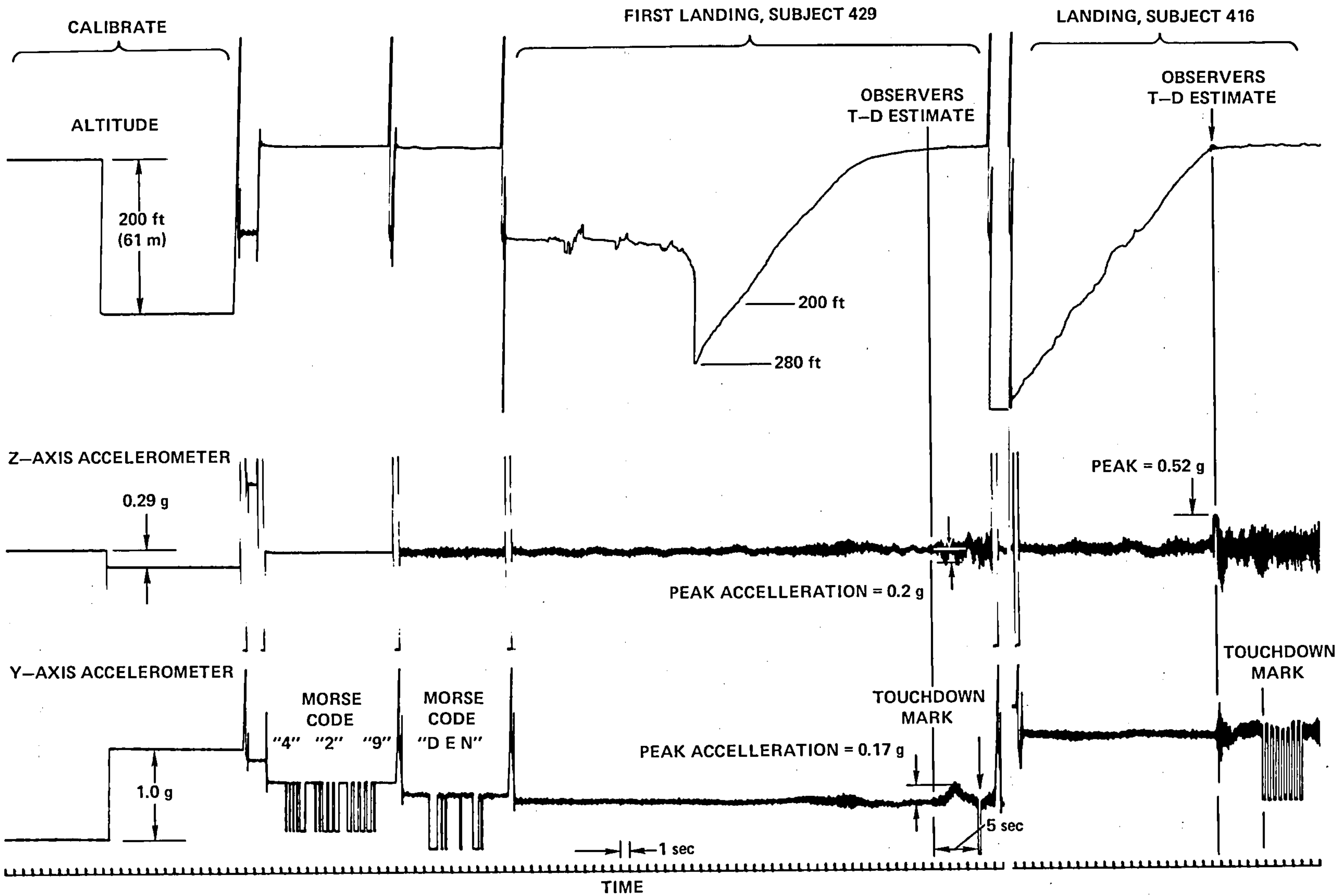

Figure 8.- Strip-chart recordings of two landings.

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
NASA TM-84229		

4. Title and Subtitle	5. Report Date
A PORTABLE, LOW-COST FLIGHT-DATA MEASUREMENT AND RECORDING SYSTEM	March 1982
	6. Performing Organization Code
7. Author(s)	8. Performing Organization Report No.
Robert J. Miller	A-8871
	10. Work Unit No.
9. Performing Organization Name and Address	T-5933
NASA Ames Research Center Moffett Field, Calif.	11. Contract or Grant No.
	13. Type of Report and Period Covered
12. Sponsoring Agency Name and Address	
National Aeronautics and Space Administration Washington, D.C. 20546	14. Sponsoring Agency Code 505-35-31

15. Supplementary Notes

Point of Contact: Robert J. Miller, Ames Research Center, MS 210-5, (415) 965-5325 or FTS 448-5325.

16. Abstract

The report describes the design of and the experience with an inexpensive, hand-portable onboard data system used to record four parameters in the final portion of the landing approach and touchdown of an airplane. The system utilized a high-quality audio tape recorder and amateur photographic equipment with accessory circuitry rather than specialized instrumentation to give satisfactory results.

17. Key Words (Suggested by Author(s))	18. Distribution Statement
Airborne instrumentation Instrumentation recorders	Unlimited Subject Category - 35

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price*
Unclassifed	Unclassified	18	A02

*For sale by the National Technical Information Service, Springfield, Virginia 22161