**NASA TECHNICAL NOTE**

**NASA TN D-8118** c.1

NASA TN D-8118

# OPTICALLY COUPLED DIGITAL ALTITUDE ENCODER FOR GENERAL AVIATION ALTIMETERS

*Floyd R. Bryant*

*Langley Research Center*
*Hampton, Va. 23665*

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION • WASHINGTON, D. C. • DECEMBER 1975

| | | |
|---|---|---|
| 1. Report No.<br>NASA TN D-8118 | 2. Government Accession No. | 3. Recipient's Catalog No. |
| 4. Title and Subtitle<br>OPTICALLY COUPLED DIGITAL ALTITUDE ENCODER FOR GENERAL AVIATION ALTIMETERS | | 5. Report Date<br>December 1975 |
| | | 6. Performing Organization Code |
| 7. Author(s)<br>Floyd R. Bryant | | 8. Performing Organization Report No.<br>L-10556 |
| | | 10. Work Unit No.<br>513-54-02-03 |
| 9. Performing Organization Name and Address<br>NASA Langley Research Center<br>Hampton, Va. 23665 | | 11. Contract or Grant No. |
| | | 13. Type of Report and Period Covered<br>Technical Note |
| 12. Sponsoring Agency Name and Address<br>National Aeronautics and Space Administration<br>Washington, D.C. 20546 | | 14. Sponsoring Agency Code |
| 15. Supplementary Notes | | |

16. Abstract

An optically coupled pressure altitude encoder which can be incorporated into commercially available inexpensive general aviation altimeters has been successfully developed. The encoding of pressure altitude is accomplished in 100-ft (30.48-m) increments from -1000 to 20 000 ft (-304.8 to 6096 m). The prototype encoders were retrofitted into two different internal altimeter configurations. A prototype encoder was checked for accuracy of transition points and environmental effects. Each altimeter configuration, with the encoder incorporated, was laboratory tested for performance and was subsequently flight-tested over the specified altitude range.

With few exceptions, the assembled altimeter-encoder met aeronautical standards for altimeters and encoders. Design changes are suggested to improve performance to meet required standards consistently.

| | | | |
|---|---|---|---|
| 17. Key Words (Suggested by Author(s))<br>Encoder-altimeter<br>Air traffic control | | 18. Distribution Statement<br>Unclassified – Unlimited<br>Subject Category 06 | |
| 19. Security Classif. (of this report)<br>Unclassified | 20. Security Classif. (of this page)<br>Unclassified | 21. No. of Pages<br>27 | 22. Price*<br>$3.75 |

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

# OPTICALLY COUPLED DIGITAL ALTITUDE ENCODER FOR GENERAL AVIATION ALTIMETERS

Floyd R. Bryant
Langley Research Center

## SUMMARY

An optically coupled pressure altitude encoder which can be incorporated into commercially available inexpensive general aviation altimeters has been successfully developed. The encoding of pressure altitude is accomplished in 100-ft (30.48-m) increments from -1000 to 20 000 ft (-304.8 to 6096 m). The prototype encoders were retrofitted into two different internal altimeter configurations. A prototype encoder was checked for accuracy of transition points and environmental effects. Each altimeter configuration, with the encoder incorporated, was laboratory tested for performance and was subsequently flight-tested over the specified altitude range.

With few exceptions, the assembled altimeter-encoder met aeronautical standards for altimeters and encoders. Design changes are suggested to improve performance to meet required standards consistently.

## INTRODUCTION

More than 100 major air terminals and 20 Federal Aviation Administration (FAA) enroute air traffic control centers are being equipped to interrogate and track aircraft automatically by using radar beacon transponders with altitude reporting capability. Most aircraft using high density terminals, controlled high density corridors, and controlled airspace above 12 500 ft (3810 m) must have the new improved transponders (4096 codes) equipped not only to identify the aircraft, but also to report automatically current altitude in 100-ft (30.48-m) increments (ref. 1). This process is known as mode C operation of the transponder. Mode C operation requires that the altitude analog information be digitized and furnished to the transponder for transmittal to the ground station. Out of the approximately 133 000 general aviation aircraft registered in 1973, approximately 44 percent were transponder equipped and approximately 1.5 percent had mode C altitude reporting capability (ref. 2).

The primary components of an altitude reporting system are shown in figure 1. The altimeter senses the outside pressure through the static-pressure source. The pressure sensor of the altimeter is an evacuated pressure capsule (bellows) which expands with increasing altitude (decreasing pressure) and which drives the pilot's indicator with mechanical linkages. The encoder converts this mechanical motion into the International Civil Aviation Organization (ICAO) special digital code used for altitude reporting. The ICAO code for encoding altitude from -1000 to 20 000 ft (-304.8 to 6096 m) required nine bits: six bits of Gray code and three bits of cyclic binary code. The six Gray-code bits encode the altitude in 500-ft (152.4-m) increments. The three bits of cyclic binary code are added to resolve the altitude information into 100-ft (30.48-m) increments. This coded information is available to the transponder at all times. When interrogated by the ground radar, the transponder transmits the altitude information supplied by the encoder to the ground display. Identification number, altitude, relative position, and airspeed are shown on the radar display. Position symbol gives distance and azimuth information, thus providing three-dimensional space information to the air traffic controllers.

Since the approximately 133 000 general aviation aircraft are equipped with inexpensive nonencoding altimeters, the Langley Research Center effort was directed toward the development of techniques and devices having the potential of low cost. These low-cost encoders could be incorporated into existing altimeters to provide automatic altitude reporting capability. Investigations of several possible methods of encoding altitude using existing types of general aviation altimeters led to the conclusion that the simplest and perhaps the least expensive method was to encode the motion of the altimeter rocking shaft using a digital shaft encoder. Of the various types of digital shaft encoders, the optically coupled type was selected. Contact type encoders were ruled out because they are subject to wear and bridging of the disk segments. Brush contacts on the segmented disk cause prohibitive drag on the altimeter mechanism. Magnetic shaft encoders are limited in resolution and require an expensive and complicated readout system. Capacitive shaft encoders require several logic processing circuits, are bulky, and have complex mechnical relating components. Optical encoders are not subject to wear problems inherent in contact devices, have extremely high accuracy and resolution, and can operate efficiently at high speed and duty cycle. Readout is accomplished by an array of carefully alined photoelectric transducers facing an altitude encoding disk having transparent and opaque segments. A light source array behind the disk provides excitation. As the disk rotates in response to the input variable, the opaque areas on the disk pass between the source and sensors, interrupting the light beam, and modulating the transducer output in accordance with the selected code and as a function of the input variable. Solid-state optical encoders are best applied where extended service life, accuracy, and resolution are mandatory, thus making optical encoders an appropriate choice for altitude encoders. The optically coupled encoding system was selected primarily as a means for minimizing load effects on the altimeter mechanism. Unlike the more expensive types of altimeters used in commercial aircraft, the general aviation altimeters are not servo driven. Direct gearing of an encoder to the altimeter mechanism has the disadvantage of increased loading of the driving aneroid capsule, especially at the higher altitudes where the pressure change per change in altitude is less.

Two differently configured altimeters, both widely used in general aviation aircraft, were selected to demonstrate that the optical encoder could be retrofitted. One configuration was chosen for those altimeters requiring a more complex encoder attachment where direct coupling was impossible because of space limitations. The second configuration allowed the optical encoder to be mounted directly to the altimeter rocking shaft.

## ENCODER DESIGN

The digital altitude encoder was designed to meet the minimum performance standards for automatic pressure altitude reporting code generating equipment, (ref. 3). In addition to the minimum performance standards, other requirements were placed upon the design. A summary of these standards and requirements is given in the appendix.

A diagram illustrating the selected altitude encoding technique is shown in figure 2. A view of a prototype unit is shown in figure 3. As shown in figure 3, the encoder consists of four components: a GaAs light source array, a slotted mask, a silicon photodetector array (parts of the detector head), and an encoding disk. The encoding disk, to be attached to the rocking shaft of a general aviation altimeter, must encode altitude in 100-ft (30.48-m) increments from -1000 to 20 000 ft (-304.8 to 6096 m) or 210 increments in approximately 26° rotation of the shaft. Only the coded segment of the disk is used because of space limitations. The width of the smallest code slit, which determined the 100-ft (30.48-m) resolutions, measures approximately 0.00520 in. (0.132 mm) with 0.00347-in. (0.09-mm) spacing. To minimize optical interference between tracks on the code disk, the various tracks were offset from one another. A total of nine tracks was required for the range of the encoder. The disk consists of 0.010-in. (0.254-mm) thick beryllium copper with a 0.001-in. (0.0254-mm) thick iron oxide deposit on each side. The thickness of the beryllium copper was such that a sharp, accurately coded slit of the width necessary to obtain the required resolution was difficult to fabricate. Therefore, slits were etched through the beryllium copper first, then a 0.001-in. (0.0254-mm) iron oxide coating was deposited on each side of the disk. A second etching process then produced sharply defined slits in the thin oxide layer. The light sources consisted of an array of gallium arsenide solid-state light sources, offset to match the offset in the encoder tracks. The photodetectors were solid-state detectors positioned opposite the light sources. The solid-state light sources and silicon detectors were chosen because of their long life, small size, low power requirements, and high shock and vibration resistance. They are readily available, inexpensive, and spectrally compatible. The relative spectral characteristics are shown in figure 4.

The slotted mask of the same material as the disk was etched to form a very narrow light beam. The width of the beam measured approximately 0.0013 in. (0.033 mm) to maintain the resolution designed into the encoding disk.

## MECHANICAL RETROFIT OF ENCODER TO ALTIMETERS

The interface between the encoders and the two different general aviation altimeters required brackets for the detector head, electrical wiring, allowing motion between the interframe and outer case, parts for mounting the encoder disk, extension of the altimeter case, and the mounting of a connector for routing the wiring to the transponder. During adjustment of the barometric pressure from 28.1 to 31.0 in. of mercury (95 to 105 kPa) the altimeter rotated approximately 900° within the altimeter case. Because the encoder was to be independent of this adjustment, it was mounted on the rotating part of the altimeters. To maintain electrical continuity between the fixed and rotating parts, a reel was used to wind up the ribbon cable.

The interface requirements for the first configuration A were more complex than those for the second configuration B, because of space limitations in the rocking-arm-shaft area. A bracket was fabricated to mount an auxiliary shaft back of and in line with the rocking arm shaft. Provisions were made to mount the encoder detector head on the same bracket. The encoding disk segment and an antibacklash spring were mounted on the auxiliary shaft which was set in low friction jewel pivots. The disk segment and hub were balanced by means of three adjustable balance screws on the hub. The auxiliary shaft was driven directly through a pin-and-yoke system attached to the rocking arm shaft of the altimeter. A view of the completed assembly without the case is shown in figure 5. The interfacing parts are shown in figure 6.

The interface requirements for altimeter configuration B were much less complex than for configuration A. The configuration was such that the encoder disk segment was attached directly to the rocking shaft of the altimeter by means of a split hub (See fig. 7). The encoder detector-head mounting bracket, wiring bracket, coil of ribbon wire, and windup reel are shown in figure 7.

## TEST PROGRAMS AND RESULTS

### Laboratory Performance Tests

A prototype encoder was tested for accuracy of the transition points by using a precision dividing head with a resolution of 0.01° and a certified accuracy of ±0.017°. All transition points fell within the ±75-ft (±22.86-m) tolerance specified in AS 8003 (ref. 3). However, the deviation spread was such as to take most of the allowed tolerance. These deviations should be small in order to allow more tolerance in the process of retrofitting the encoder to an altimeter. A careful investigation of all the transition points showed that the artwork and the etching process were accurately accomplished and that the largest deviations were caused by the relative geometric misalinement of the detector-head components (light source, source mask, and photodetectors). More precise alinement of these components would bring the deviations to within ±50 ft (±15.24 m). The encoder operated satisfactorily at the specified voltages; the power consumed when it was operated at 15 volts was 0.75 watts.

Other tests were conducted on one each of the two different configurations of assembled encoder-altimeters from -1000 to 20 000 ft (-304.8 to 6096 m). These tests included measurements of scale error, hysteresis, friction errors, position effects, barometric scale error, and correspondence between altimeter dial reading and encoder digital display. Minimum performance standards for pressure-operated altimeters are given in reference 4. Minimum performance standards for automatic reporting code generating equipment are given in reference 3. The test apparatus used in conducting these tests was a Kollsman precision pressure monitor with a resolution of 0.0001 in. of mercury (0.34 Pa) and an accuracy of 0.001 in. of mercury (3.4 Pa). The pressure-sensing element of the monitor is an electron-beam-welded aneroid capsule which oscillates at its natural frequency in the air gap of a magnetic circuit. The capsule is evacuated and the outside is exposed to the test pressure. The pressure change acting on the capsule results in a change of its natural frequency; this frequency is the output signal. The pressure is controlled by a Kollsman precision controller with a resolution exceeding 0.001 in. of mercury (3.4 Pa). Vernier controls connected to a set of precision valves permit the sensitive adjustment of the controller. Self-regulating valves detect any change in the output through pressure-sensing diaphragms and maintain the pressure at the set value.

Altimeter-encoder, configuration A.- Results of the tests on this configuration are given in tables I and II.

(a) Friction errors were out of tolerance in some instances from 5 to 40 ft (1.52 to 12.2 m), with the larger errors occurring at the higher altitudes. These errors, especially at the higher altitudes where a smaller change in pressure obtained for a given altitude change, were probably caused by friction imposed on the altimeter mechanism by the auxiliary shaft on which the code disk segment is attached. In this configuration (as discussed before), the auxiliary shaft mounted in jewel bearings was driven through a connecting pin and yoke by the rocking shaft which is attached to the aneroid capsule through mechanical linkages. The lack of space of this configuration prevented mounting the code disk directly on the rocking shaft.

(b) Scale error was out of tolerance by 10 ft (3.05 m) at -1000 ft (-304.8 m) and at 0 ft (0 m). These errors are a result of a small error in the zero adjustment of the altimeter and can be corrected by readjustments of the zero position.

(c) As shown in table I, hysteresis was within the allowed tolerance of ±75 ft (±22.86 m).

(d) Encoder readings were correct for the altitudes that were checked.

(e) Position effects were checked at $0^{\circ}$, $90^{\circ}$, $180^{\circ}$, and $270^{\circ}$ at sea level conditions. An encoder error of 100 ft (30.48 m) was noted at $180^{\circ}$. When the instrument was tapped lightly, it could be observed that the encoder was near its zero transition point; it could have been within tolerance since the allowed error in the transition points was ±75 ft (±22.86 m), and the resolution of the encoder (one increment) was 100 ft (30.48 m). When the altimeter was adjusted to a point half way between transition points, no position effects were obtained. Position effects on the altimeter indication were within the specified ±20 ft (±6.096 m).

(f) The results of the barometric scale adjustment (from ref. 4) are given in table II. As shown, the altimeter indications were within the specified ±25 ft (±7.62 m). The encoder was off one increment, or 100 ft (30.48 m), at four settings of the baroset knob. Since the altimeter was within the specified tolerance, the detector head of the encoder must have been displaced with reference to the coded disk segment. The ribbon cable allowing the altimeter to be rotated within the case during this adjustment could have had enough drag to distort the detector-head mounting bracket to a point where the distortion could cause this displacement. The cable is attached directly to the detector-head mounting bracket. Binding of the fixed and rotating sections of the cable windup reel could also cause the displacement since the rotating section is also attached to the detector mounting bracket and the fixed section to the case. Using a smaller, more flexible cable, adjusting the clearance between the two sections of the windup reel, or making the mounting bracket more rigid would correct this problem.

(g) Correspondence, defined as the difference in the altimeter dial indication and the encoder digital output was checked at each transition point over the range of the encoder, -1000 to 20 000 ft (-304.8 to 6096 m). Approximately 1.7 percent of the 420 data points were outside the allowable correspondence tolerance of ±125 ft (±38.1 m) by a small amount, 5 to 25 ft (1.52 to 7.62 m). The data indicated a nonlinearity with altitude, resulting in an additional spread in the transition points of approximately 50 ft (15.24 m) over that of the encoder. A check of the individual code tracks showed that all tracks were nonlinear by about the same amount. The nonlinearity is attributed to a slight displacement of the auxiliary shaft axis from the rocking-shaft axis. A displacement of 0.008 in. (0.2 mm) would account for the magnitude of the nonlinearity obtained over the range of the encoder. More precise alinement of the auxiliary shaft axis would correct for the nonlinearity and would bring all correspondence data points within specified limits.

Altimeter-encoder, configuration B.- Results of the test on altimeter-encoder configuration B are given in table III.

(a) Frictional errors were out of tolerance at the higher altitudes (lower pressure). These errors were probably caused by additional friction on the rocking-shaft pivots because of the added weight of the encoder hub and disk assembly. The use of higher quality jewels and pivots for mounting and proper adjustment of the rocking arm shaft could help minimize this problem.

(b) Scale factor errors were outside the allowed tolerance by a small amount at two altitudes: 10 ft (3.048 m) at a -1000-ft (-304.8-m) altitude and 20 ft (6.1 m) at a 500-ft (152.4-m) altitude. Readjustment of the altimeter zero would eliminate this offset.

(c) Hysteresis was within specification.

(d) Encoder readings were correct at the altitudes checked.

(e) Position effects were checked in normal operating position and at $90^{\circ}$, $180^{\circ}$, and $270^{\circ}$. No change in encoder reading was observed. Altimeter was within the ±20 ft (±6.096 m) tolerance specified in reference 4.

(f) No change in encoder reading was obtained while varying the barometric scale from 28.1 to 31.0 in. Hg (95 to 105 kPa).

(g) Correspondence, previously defined as the difference in the altimeter dial indication and the encoder digital output, was checked at each transition point over the range of the encoder, -1000 to 20 000 ft (-304.8 to 6096 m). Since the encoder was attached directly to the rocking shaft of the altimeter in this configuration, the nonlinearity experience in configuration A was not present. Five of the 420 data points were outside the allowable limits of ±125 ft (±38.1 m) by a small amount, 5 to 45 ft (1.52 to 13.716 m), because the altimeter scale factor was off zero at zero altitude. As discussed earlier, to correct the scale factor of the altimeter requires a shift of the altimeter zero adjustment in the positive direction. This correction would also bring the correspondence data within the allowable tolerance of ±125 ft (±38.1 m).

## Qualification Tests

Encoder-altimeter configuration A was environmentally tested to the specifications of the altimeter (ref. 4). These tests included high- and low-temperature operation, extreme temperature exposure, humidity, and vibration. Because of the simplicity of configuration B, it was tested for vibration effects only.

High- and low-temperature operation.- The altimeter-encoder was tested at -30° C and 50° C. The assembly was maintained at each of these temperatures for 3 hours before calibration. Calibration at 50° C showed the altimeter to be within specified performance standards. No significant effects were noted in the encoder transition points in comparison to those points at a room temperature of 20° C.

Calibration at -30° C showed that hysteresis and friction of the altimeter were within specifications. However, the scale factor was out of tolerance by 10 ft (3.048 m) at the 500-ft (152-m) level, 20 ft (6.096 m) at 0 level, and 40 ft (12.192 m) at the 20 000-ft (6096-m) level.

The span from transition point to transition point of the encoder varied from 15 to 25 ft (4.57 to 7.62 m) from room temperature readings with the exception of one point which differed by 40 ft (12.19 m). The measured error of 15 to 25 ft (4.57 to 7.62 m) is of the same order as the repeatability of the transition-point readings at room temperature.

Extreme temperature operation.- The altimeter-encoder assembly was exposed to ambient temperatures of -65° C and 70° C for periods of 24 hours each. Three hours after exposure had been completed, calibrations showed no adverse effects on the altimeter or encoder.

Humidity test.- The instrument was mounted in a humidity chamber in its normal operating position with a 10-ft (3.048-m) coil of copper tubing connected to the static-pressure port to simulate installation conditions. Tubing was positioned so that moisture would drain out the open end. The chamber was maintained at a temperature of 70° C and a relative humidity of 95 percent for a period of 6 hours. The heat was then shut off and the instrument was allowed to cool for a period of 18 hours in this atmosphere. During this time, the humidity rose to 100 percent as the temperature decreased to 38° C. Calibration was then made at room temperature and compared with calibration made at room temperature before humidity tests. The altimeter was within specification and no effects were noted on the encoder.

Vibration tests.- The assembled altimeter-encoders, one of each configuration, were tested for vibration effects. A resonant frequency survey was made from 5 to 500 Hz. Maximum acceleration in the range of 5 to 50 Hz was 1.5 g; in the range of 50 to 500 Hz, maximum acceleration was 0.5 g. A slight resonance was noted at 50 Hz for each configuration. Both units were vibrated at 50 Hz in three axes for 2 hours each. The altimeters were recalibrated and were within specifications. In configuration B, where the encoder disk was attached directly to the rocking shaft of the altimeter, the encoder showed no significant effects. In configuration A, where the encoder disk was attached to an auxiliary shaft in line with the rocking shaft and driven by the rocking shaft with a mechanical linkage, the encoder had deviated approximately 40 ft (12.19 m) in the negative direction. It was found that the clamping device connecting the auxiliary drive shaft to the altimeter rocking shaft was not properly tightened. The clamping device was tightened and the assembly was subjected to 30 hours of aircraft structure vibration during the flight tests.

## Flight Tests

One each of the two altimeter-encoder configurations was mounted in a small twin-engine aircraft and was flight-tested. The tests were conducted to determine the performance of the encoders. The performance was evaluated through measurements of the correspondence at various altitudes.

The flight-test setup is shown in figure 8. The pressure source $P_s$ of the altimeter was a line connected to the copilot's static-pressure line. The altitude (ICAO) code output of the encoder was converted to binary coded decimal (BCD) and displayed on the digital light panel. As shown, the observer read and recorded the two altimeter dial indications and their corresponding encoder digital outputs. Figure 9 shows the flight package as it was installed in the aircraft for the flight tests.

On one flight from 0 to 20 000 ft (0 to 6096 m), correspondence was measured at 1100-ft (335.28-m) levels during both ascent and descent. The six most significant bits of the code are in the Gray code and the position of the code changes once for every 500-ft (152.4-m) increment. The three least significant bits encode the altitude in 100-ft (30.48-m) increments. The 1100-ft (335.28-m) increments, rather than 500- or 1000-ft (152.4- or 304.8-m) increments, were chosen to utilize all nine bits of the encoder. Four other data flights were made from 0 to 9000 ft (0 to 2743 m). Ten to thirty data points were taken per flight. The altimeter-encoders were subjected to 30 hours of flight time spread over a 27-day period.

Plots of the correspondence data obtained during the 0- to 20 000-ft (0- to 6096-m) flight are shown in figures 10 and 11. Some data points were outside the allowable tolerance of ±125 ft (±38.1 m) in both configurations.

Configuration A flight data and transition-point data taken after the flight tests showed a shift in the encoder zero from that point obtained before the flight tests. Examination of all the flight data indicated that there was a gradual shift over the period during which the flights were made. A scale factor calibration of the altimeter before and after the flights showed no zero shift in the altimeter. Therefore, it was concluded that a relative displacement of the detector head and encoder disk had taken place; this displacement was similar to that obtained during laboratory vibration tests. A more positive means of securing the clamp on the altimeter rocking shaft would prevent this gradual shift in encoder zero caused by vibration.

Configuration B flight data and transition-point data taken after the flight tests also indicated a zero shift in the encoder from that point obtained before the flight tests. A calibration of the altimeter scale factor before and after the flights indicated an altimeter zero shift of the same magnitude and direction as with the encoder. The unit was vibrated to the specifications as given in reference 4 after the flight test; no further zero shift was obtained. Therefore, it was concluded that a shock during installation or vibration during flight testing may have introduced the zero shift. The instruments were mounted on brackets attached directly to the airframe and possibly encountered vibrations greater than those received during laboratory testing. Rezeroing the altimeter would bring the flight data within the allowable limits.

## CONCLUDING REMARKS

Optically coupled pressure altitude encoders were designed, fabricated, and retrofitted to existing general aviation altimeters for encoding the analog indication of the altimeters into the international code used in automatic altitude reporting. The encoders were designed for operation from -1000 to 20 000 ft (-304.8 to 6096 m).

Laboratory and flight tests were conducted on two of the prototype encoders installed in two differently configured general aviation altimeters. With few exceptions, the prototype encoders installed in the altimeters operated satisfactorily and within specified tolerances. Most of the problems occurred during the retrofitting process. Comments concerning improvements in the altimeter-encoder combinations so that production units could meet required standards follow:

1. Mounting brackets (as in configuration A) should be fabricated in one piece for greater rigidity.

2. Care must be exercised in the alinement of the auxiliary shaft axis with the rocking-arm-shaft axis of the altimeter (as in configuration A) to minimize nonlinearity in the encoder output.

3. A positive means of securing the clamp on the rocking shaft (as in configuration A) should be provided to prevent a shift in encoder zero during vibrations.

4. A separate mounting bracket should be used for mounting the wiring connector board (as in configuration B). The wiring connector board is now attached directly to the encoder detector head. The ribbon cable and a part of the windup reel are attached to this board and during adjustment of the baroset setting could put a strain on the connector board; such a strain would result in a displacement of the detector head relative to the encoder disk.

5. More accurate geometric alinement of the detector-head parts would lessen the spread in the transition points and would permit greater tolerance in the retrofitting of the encoders to the altimeters in each of the two configurations.

6. A means of externally zeroing the encoders should be provided in each of the altimeter configurations.

7. Care should be exercised in selecting jewels and pivots to minimize frictional effects.

Langley Research Center
National Aeronautics and Space Administration
Hampton, Va. 23665
December 12, 1975

# APPENDIX

## ENCODER SPECIFICATIONS

The specifications for the encoder are as follows:

(1) The encoder must comply with the minimum performance standard (from ref. 3) summarized below.

  (a) Code: International Civil Aviation Organization (ICAO) altitude transmission code

  (b) Resolution: 100-ft (30.48-m) increments

  (c) Accuracy:

    Correspondence: ±125 ft (±38.1 m) (correspondence between the encoder output and the altimeter reading used to maintain flight altitude when referenced to 29.921 in. of mercury (101.31 kPa))

    Transition points: ±75 ft (±22.86 m) (When a transition from one encoded output to the next encoded output occurs, the displayed pressure altitude, when referenced to 29.921 in. of mercury (101.31 kPa), must be within ±75 ft (±22.86 m) of the nominal pressure altitude for that transition point.)

  (d) Zero-foot altitude reference: 29.921 in. of mercury (101.31 kPa)

  (e) Encoded output: In accordance with U.S. Standard Pressure Altitude Tables, 1962

  (f) Environmental specifications: Same as altimeter of which encoder is a part (ref. 4)

(2) Special requirements.

  (a) The encoder must be of optical design with the capability of being mechanically attached to general aviation altimeters.

  (b) The encoder must have a potential for low cost fabrication and retrofitting to general aviation altimeters.

  (c) The encoder must have a range of -1000 to 20 000 ft (-304.8 to 6096 m).

  (d) The encoder must have a voltage operating range of 13.5 to ±1.5 volts dc.

# REFERENCES

1. Designation of Federal Airways, Area Low Routes, Controlled Airspace, and Reporting Points. Federal Register, vol. 38, no. 106, June 4, 1973.
2. Drouilhet, Paul R., Jr.: The Development of the ATC Radar Beacon System: Past, Present, and Future. IEEE Trans. Communications, vol. Com-21, no. 5, May 1973, pp. 408-421.
3. Minimum Performance Standard for Automatic Pressure Altitude Reporting Code Generating Equipment. AS 8003, Soc. Automot. Eng., July 1974.
4. Altimeter, Pressure Actuated Sensitive Type. AS 392C, Soc. Automot. Eng., Feb. 1959.

TABLE I.- RESULTS OF LABORATORY PERFORMANCE TEST ON ALTIMETER-ENCODER, CONFIGURATION A

[Allowed errors are specified in reference 4]

| Altitude | | Frictional error | | Allowed frictional error | | Scale error | | Allowed scale error | | Hysteresis | | Allowed hysteresis | | Encoder reading | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ft | m | ft | m | ft | m | ft | m | ft | m | ft | m | ft | m | ft | m |
| -1 000 | -304.8 | -70 | -21.34 | 70 | 21.34 | -30 | -9.14 | ±20 | ±6.10 | 30 | 9.14 | 75 | 22.86 | -1 000 | -304.8 |
| 0 | 0 | -70 | -21.34 | 70 | 21.34 | -30 | -9.14 | ±20 | ±6.10 | 50 | 15.24 | 75 | 22.86 | 0 | 0 |
| 500 | 152.4 | -80 | -24.38 | 70 | 21.34 | -20 | -6.10 | ±20 | ±6.10 | 40 | 12.19 | 75 | 22.86 | 500 | 152.4 |
| 1 000 | 304.8 | -90 | -27.43 | 70 | 21.34 | -10 | -3.05 | ±20 | ±6.10 | 40 | 12.19 | 75 | 22.86 | 1 000 | 304.8 |
| 3 000 | 914.4 | -75 | -22.86 | 70 | 21.34 | 10 | 3.05 | ±30 | ±9.14 | 55 | 16.76 | 75 | 22.86 | 3 000 | 914.4 |
| 5 000 | 1524.0 | -80 | -24.38 | 70 | 21.34 | 20 | 6.10 | ±80 | ±24.38 | 60 | 18.29 | 75 | 22.86 | 5 000 | 1524.0 |
| 10 000 | 3048.0 | -100 | -30.48 | 80 | 24.38 | 20 | 6.10 | ±80 | ±24.38 | 60 | 18.29 | 75 | 22.86 | 10 000 | 3048.0 |
| 15 000 | 4572.0 | -100 | -30.48 | 90 | 27.43 | 0 | 0 | ±105 | ±32.00 | | | | | 15 000 | 4572.0 |
| 20 000 | 6096.0 | -140 | -42.67 | 100 | 30.48 | -10 | -3.05 | ±130 | ±39.62 | | | | | 20 000 | 6096.0 |

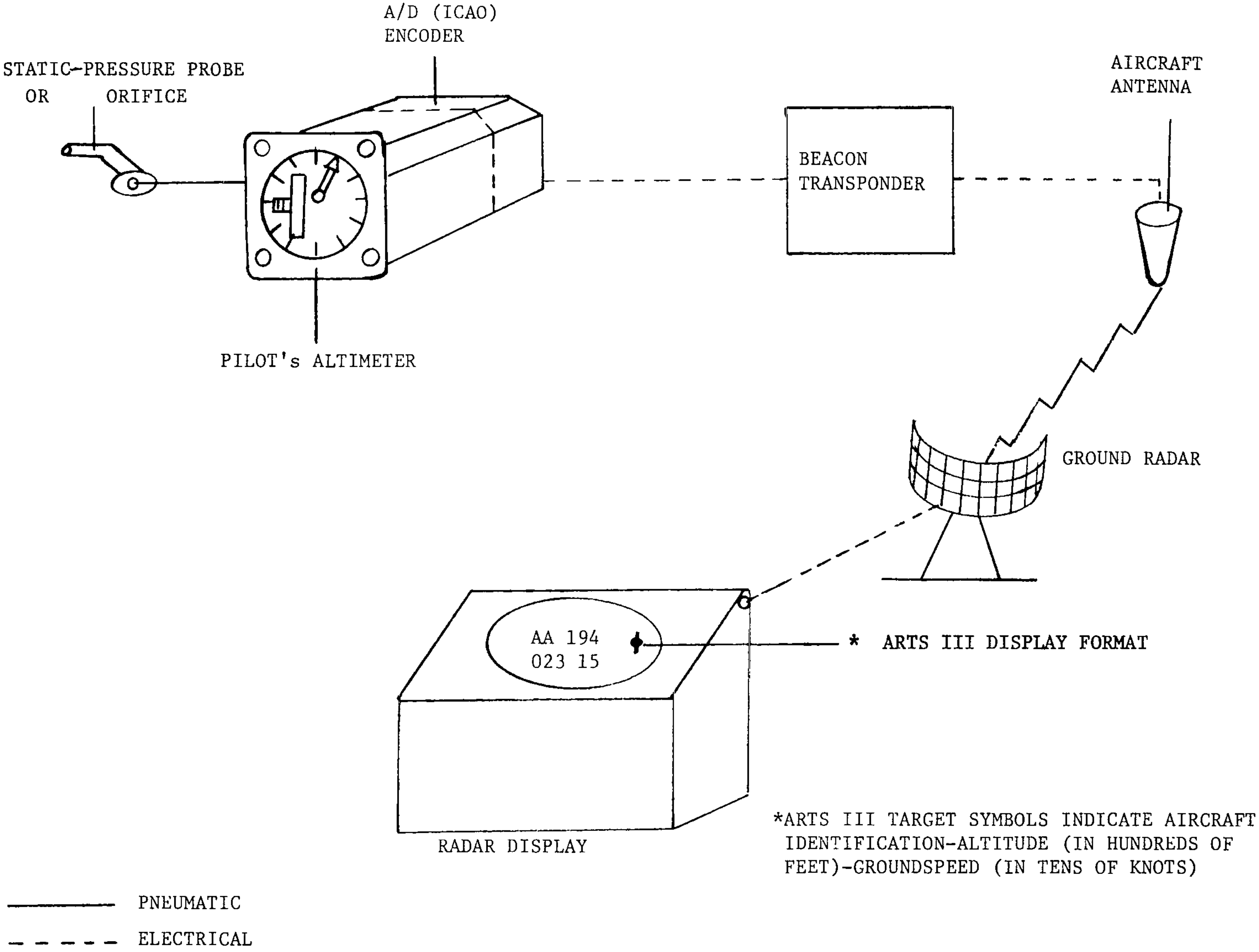
## TABLE II.- BAROMETRIC SCALE ERROR ALTIMETER-ENCODER, CONFIGURATION A

| Display | | Correct differences | | Tolerance | | Altimeter indication | | Encoder reading | |
|---|---|---|---|---|---|---|---|---|---|
| in. Hg | kPa | ft | m | ft | m | ft | m | ft | m |
| 28.10 | 95.5 | -1727 | -526.4 | ±25 | ±7.62 | -1730 | -527.3 | 0 | 0 |
| 28.50 | 96.5 | -1340 | -408.4 | ±25 | ±7.62 | -1335 | -406.9 | 0 | 0 |
| 29.00 | 98.2 | -863 | -263.0 | ±25 | ±7.62 | -880 | -268.2 | 100 | 30.48 |
| 29.50 | 99.9 | -392 | -119.2 | ±25 | ±7.62 | -390 | -118.9 | 0 | 0 |
| 29.92 | 101.3 | 0 | 0 | 0 | 0 | 0 | 0 | -100 | -30.48 |
| 30.06 | 101.8 | 129 | 39.3 | ±25 | ±7.62 | 110 | 33.5 | -100 | -30.48 |
| 30.50 | 103.3 | 531 | 161.8 | ±25 | ±7.62 | 530 | 161.5 | 0 | 0 |
| 30.90 | 104.6 | 893 | 272.2 | ±25 | ±7.62 | 900 | 274.3 | 0 | 0 |
| 30.99 | 104.9 | 974 | 296.9 | ±25 | ±7.62 | 965 | 294.1 | -100 | -30.48 |

TABLE III.- RESULTS OF LABORATORY PERFORMANCE TESTS ON ALTIMETER-ENCODER, CONFIGURATION B

[Allowed errors are specified in reference 4]

| Altitude | | Frictional error | | Allowed frictional error | | Scale error | | Allowed scale error | | Hysteresis | | Allowed hysteresis | | Encoder reading | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ft | m | ft | m | ft | m | ft | m | ft | m | ft | m | ft | m | ft | m |
| -1 000 | -304.8 | -50 | -15.24 | 70 | 21.34 | -30 | -9.14 | ±20 | ±6.10 | 50 | 15.24 | 75 | 22.86 | -1 000 | -304.8 |
| 0 | 0 | -40 | -12.19 | 70 | 21.34 | -20 | -6.10 | ±20 | ±6.10 | 10 | 3.05 | 75 | 22.86 | 0 | 0 |
| 500 | 152.4 | -30 | -9.14 | 70 | 21.34 | -40 | -12.19 | ±20 | ±6.10 | 20 | 6.10 | 75 | 22.86 | 500 | 152.4 |
| 1 000 | 304.8 | -50 | -15.24 | 70 | 21.34 | -15 | -4.57 | ±20 | ±6.10 | 15 | 4.57 | 75 | 22.86 | 1 000 | 304.8 |
| 3 000 | 914.4 | -30 | -9.14 | 70 | 21.34 | -10 | -3.05 | ±30 | ±9.14 | 20 | 6.10 | 75 | 22.86 | 3 000 | 914.4 |
| 5 000 | 1524.0 | -50 | -15.24 | 70 | 21.34 | -10 | -3.05 | ±37 | ±11.28 | 20 | 6.10 | 75 | 22.86 | 5 000 | 1524.0 |
| 10 000 | 3048.0 | -90 | -27.43 | 80 | 24.38 | -30 | -9.14 | ±80 | ±24.38 | 20 | 6.10 | 75 | 22.86 | 10 000 | 3048.0 |
| 15 000 | 4572.0 | -120 | -36.58 | 90 | 27.43 | -70 | -21.34 | ±105 | ±32.00 | 20 | 6.10 | 75 | 22.86 | 15 000 | 4572.0 |
| 20 000 | 6096.0 | -175 | -53.34 | 100 | 30.48 | -45 | -13.72 | ±130 | ±39.62 | | | | | 20 000 | 6096.0 |



*ARTS III TARGET SYMBOLS INDICATE AIRCRAFT IDENTIFICATION-ALTITUDE (IN HUNDREDS OF FEET)-GROUNDSPEED (IN TENS OF KNOTS)

Figure 1.- Primary components of an automatic altitude reporting system.

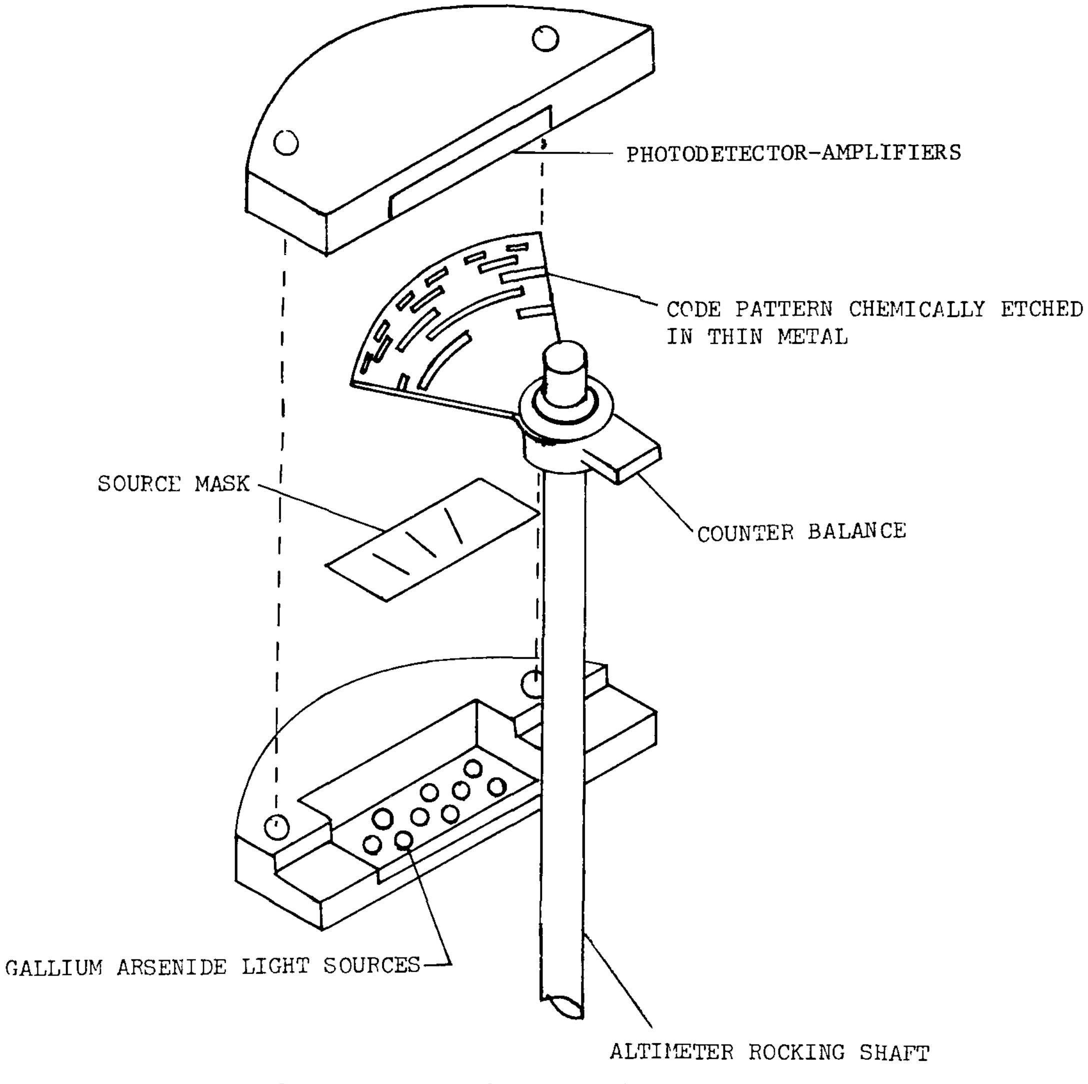
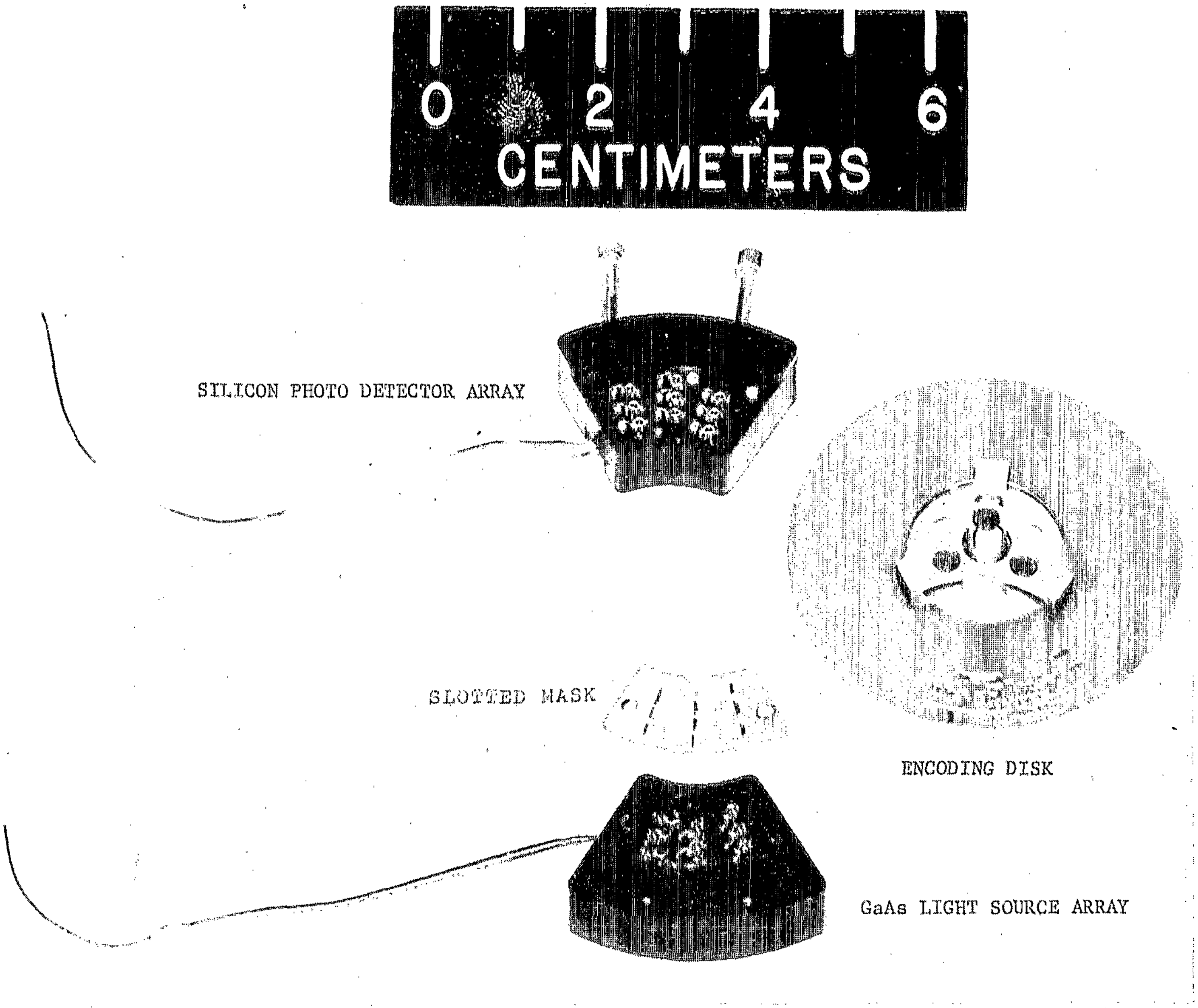


Figure 2.- Schematic diagram of an altitude-encoder.



L-74-7057.1

Figure 3.- Photograph of altitude-encoder components.

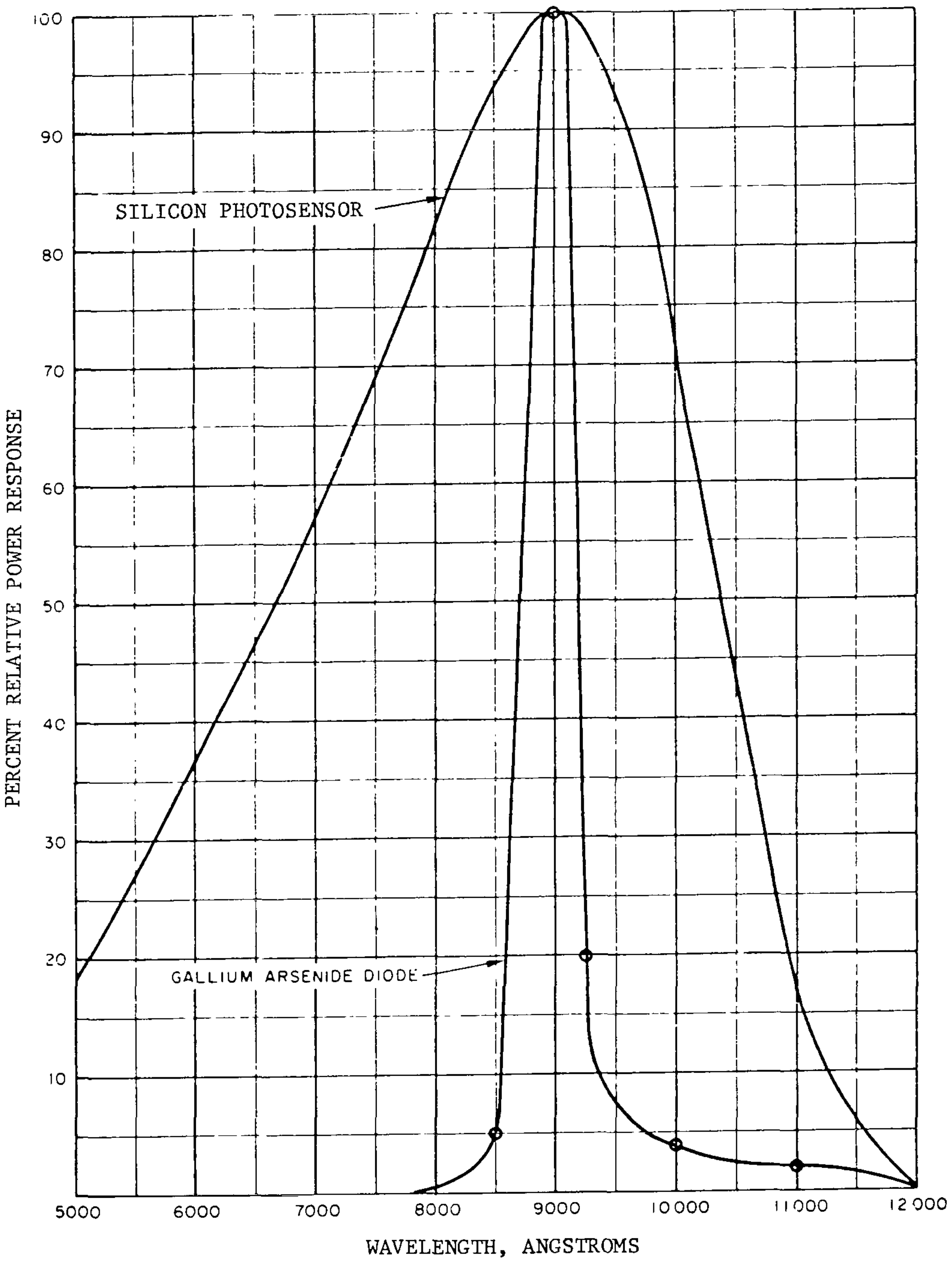
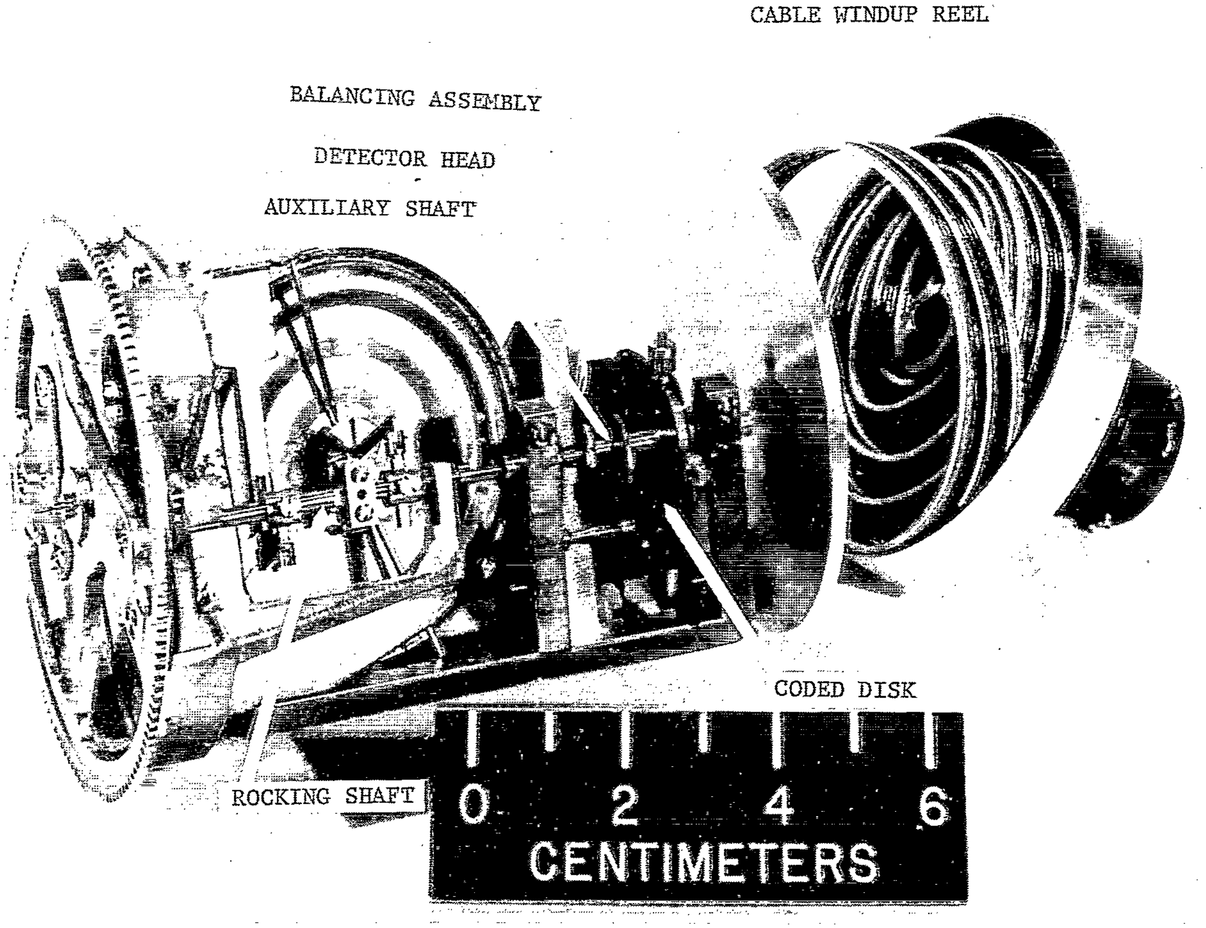
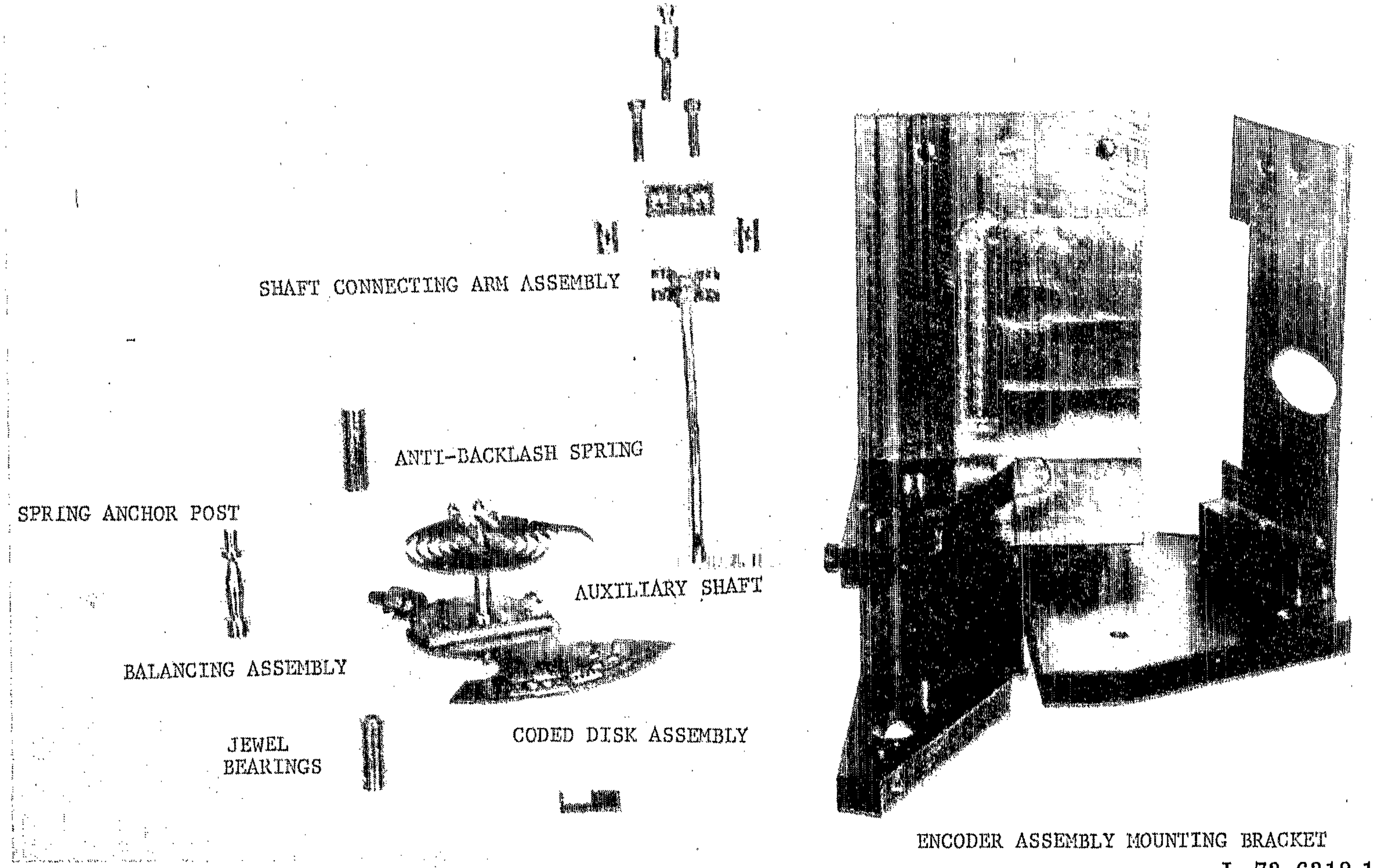


Figure 4.- Spectral response of silicon photosensor and gallium arsenide diode.



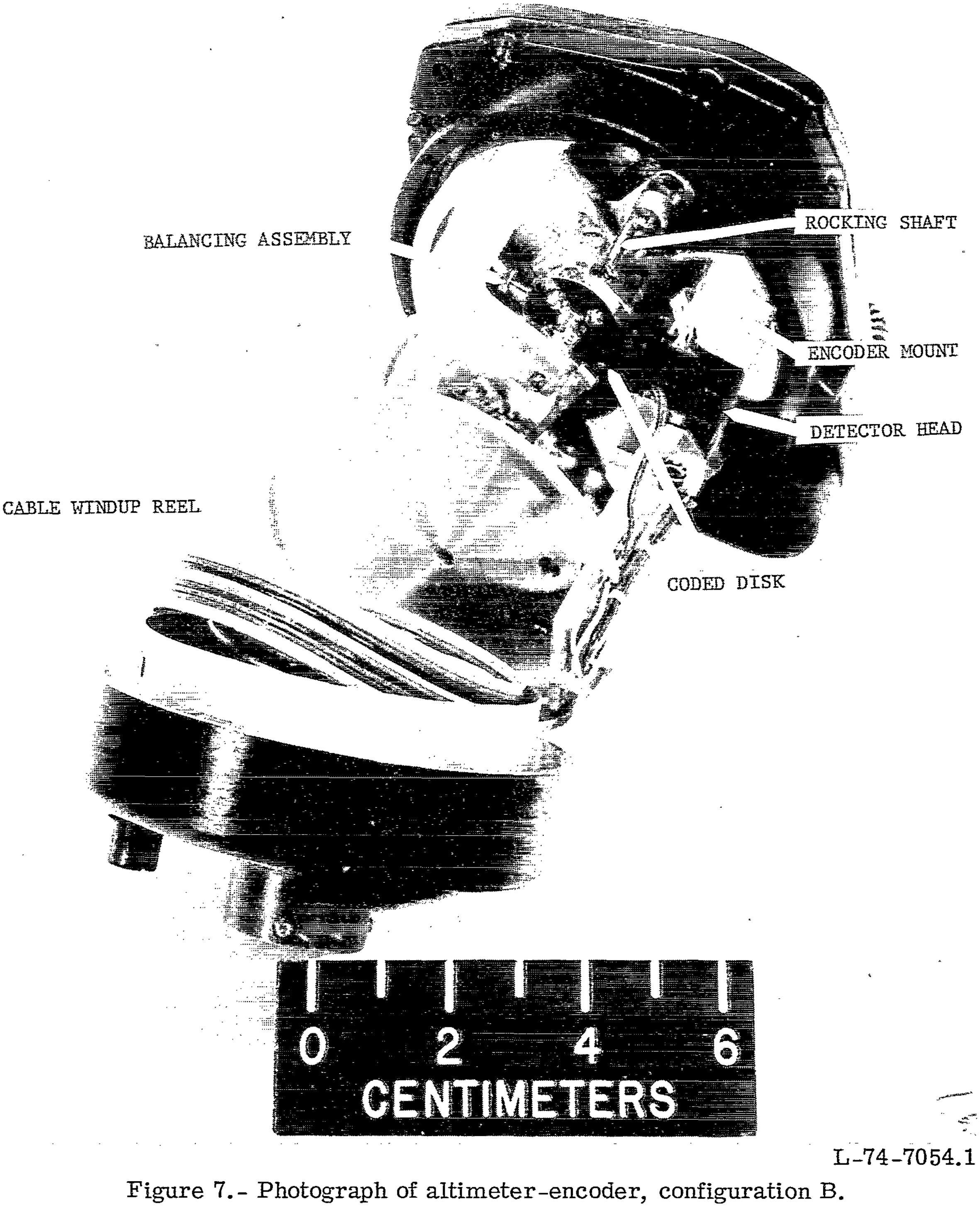
L-74-7052.1

Figure 5.- Photograph of altimeter-encoder, configuration A.



L-73-6318.1

Figure 6.- Photograph of retrofit components for altimeter-encoder, configuration A.



L-74-7054.1

Figure 7.- Photograph of altimeter-encoder, configuration B.

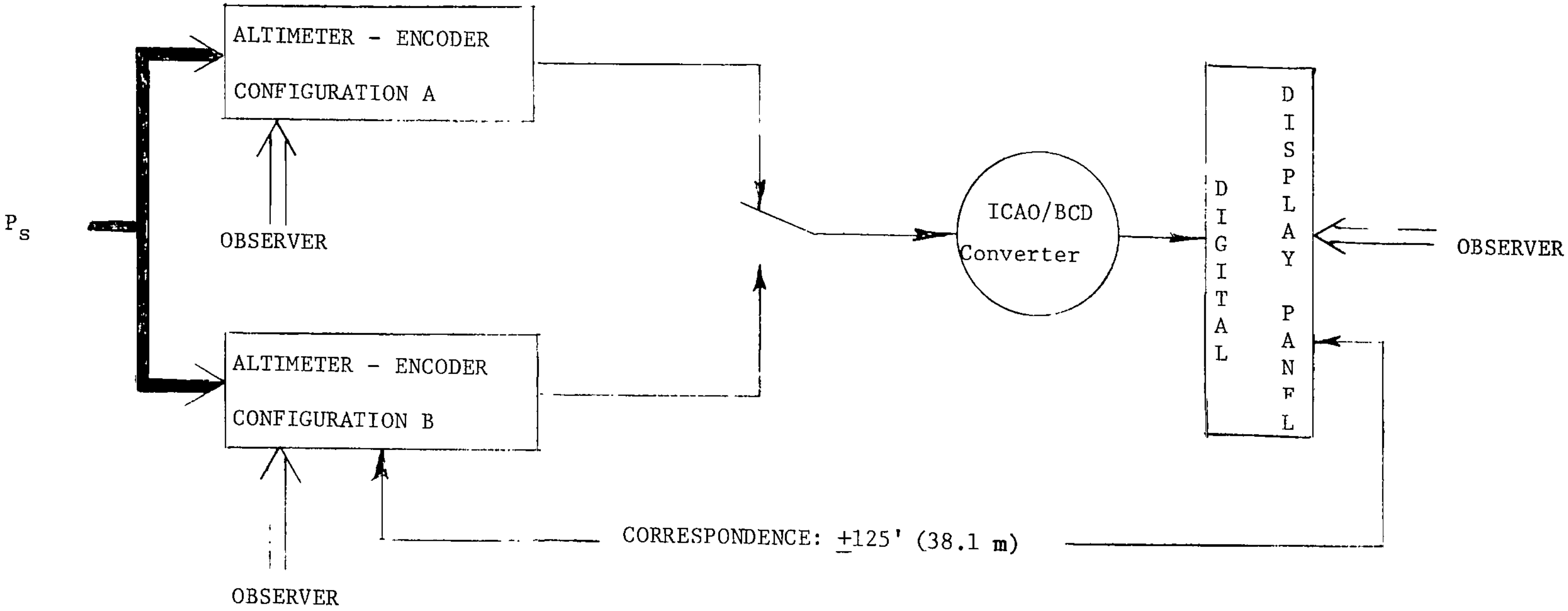
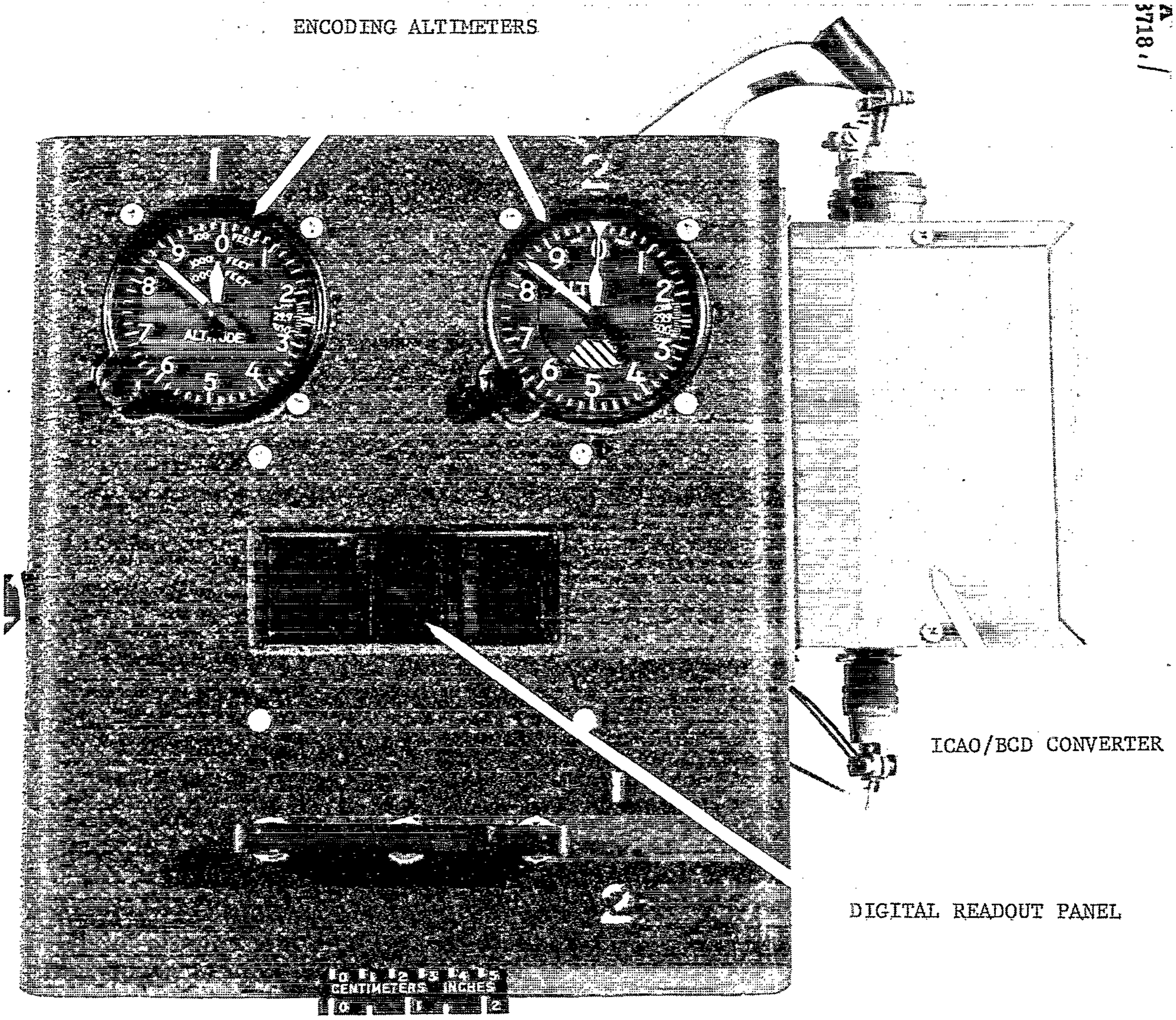


Figure 8.- Block diagram of flight-test instrumentation.



L-74-8718.1

Figure 9.- Photograph of altimeter-encoder flight-test assembly.

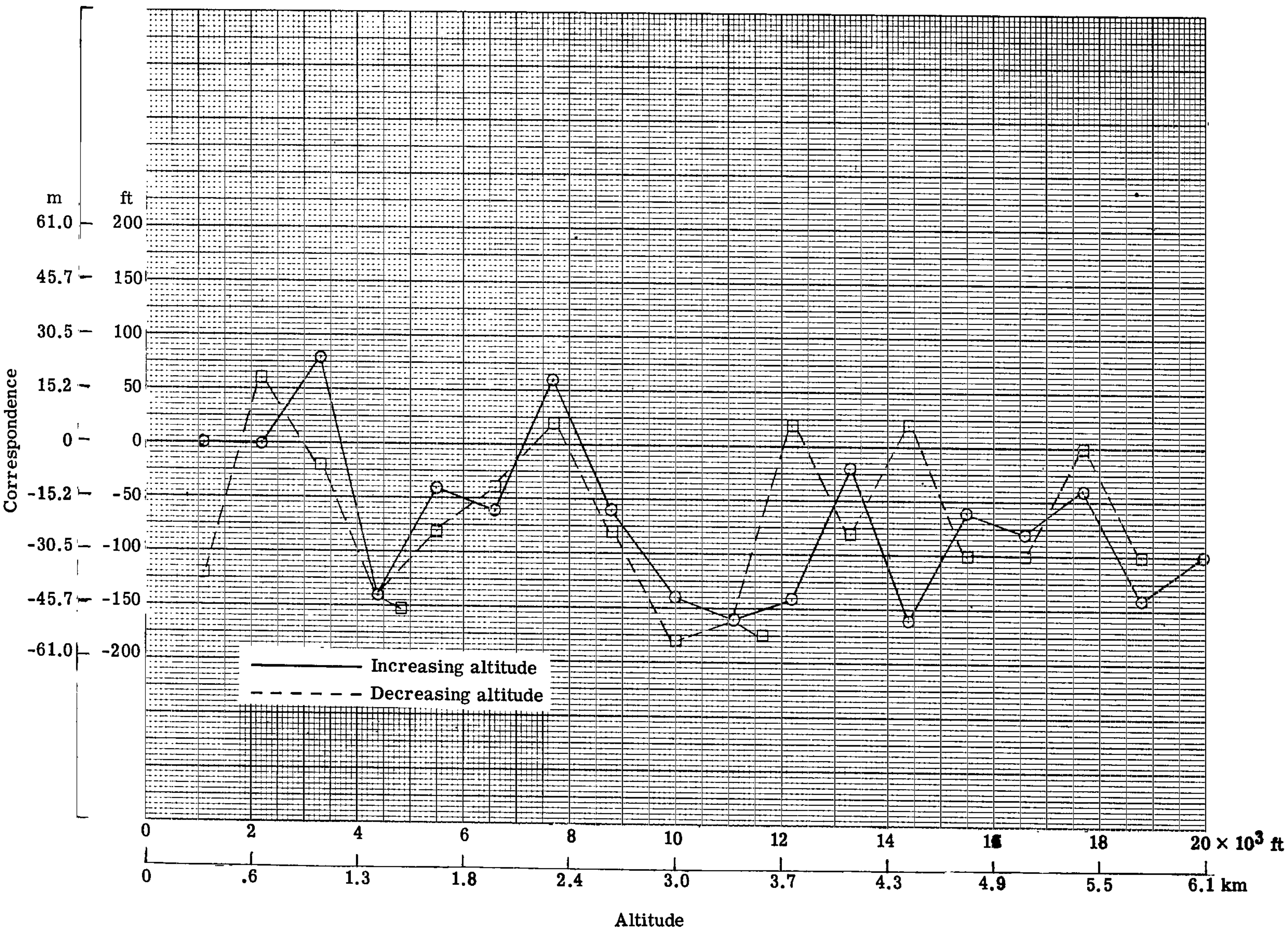


Figure 10.- Correspondence of altimeter reading and encoder output during flight tests, configuration A.

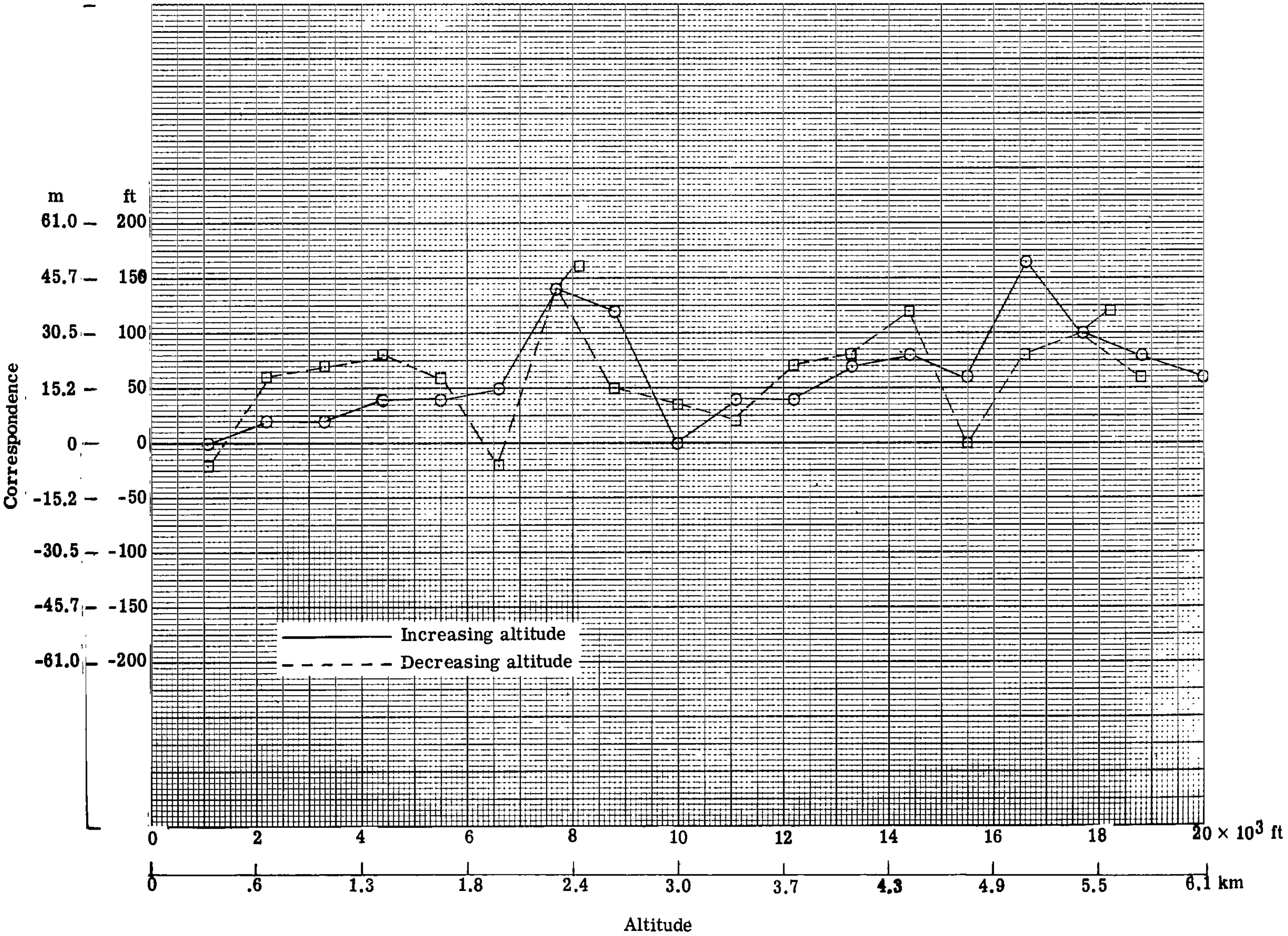


Figure 11.- Correspondence of altimeter reading and encoder output during flight tests, configuration B.

NASA-Langley, 1975 L-10556

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
WASHINGTON, D.C. 20546

OFFICIAL BUSINESS
PENALTY FOR PRIVATE USE $300

SPECIAL FOURTH-CLASS RATE
BOOK

POSTAGE AND FEES PAID
NATIONAL AERONAUTICS AND
SPACE ADMINISTRATION
451

U.S.MAIL

160 001 C1 U A 760101 S00903DS
DEPT OF THE AIR FORCE
AF WEAPONS LABORATORY
ATTN: TECHNICAL LIBRARY (SUL)
KIRTLAND AFB NM 87117

**POSTMASTER:** If Undeliverable (Section 158 Postal Manual) Do Not Return

> *"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. Also includes conference proceedings with either limited or unlimited distribution.

CONTRACTOR REPORTS: Scientific and technical information generated under a NASA contract or grant and considered an important contribution to existing knowledge.

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

SPECIAL PUBLICATIONS: Information derived from or of value to NASA activities. Publications include final reports of major projects, monographs, data compilations, handbooks, sourcebooks, and special bibliographies.

TECHNOLOGY UTILIZATION PUBLICATIONS: Information on technology used by NASA that may be of particular interest in commercial and other non-aerospace applications. Publications include Tech Briefs, Technology Utilization Reports and Technology Surveys.

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

**SCIENTIFIC AND TECHNICAL INFORMATION OFFICE**
**NATIONAL AERONAUTICS AND SPACE ADMINISTRATION**
**Washington, D.C. 20546**