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REPEATABILITY, DRIFT, AND AFTEREFFECT OF THREE TYPES OF AIRCRAFT ALTIMETERS

By William Gracey and Richard E. Stell

Langley Research Center
Langley Field, Va.

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SUMMARY

In a series of laboratory tests of a number of sensitive altimeters (Air Force type C-12 and C-13) and of precision altimeters (Air Force type MA-1), the repeatability was determined for the full range of each type of instrument, the drift characteristics were determined during 1-hour periods at various altitudes, and the drift and aftereffect were measured for a variety of simulated flights representative of some civil and military operations.

For comparable altitude ranges, the repeatability errors of the C-12 and C-13 types were generally of the same order while those of the MA-1 type were somewhat smaller. The drift and aftereffect of the C-12 instruments were smaller than those of the C-13 instruments, and the drift and aftereffect of the MA-1 altimeters were considerably smaller than those of both types of the sensitive instruments. The drift of each of the three types of altimeters was found to increase with altitude and the drift of the precision type was found to increase with increasing rate of altitude change preceding the drift test.

INTRODUCTION

The dial-type altimeters available for operational use in civil and military aircraft at the present time may be divided into two main classes: those having the sensitive-type aneroid-linkage mechanism, and those having the more recently developed precision-type mechanism. The sensitive instruments are built with 35,000-, 50,000-, and 80,000-foot ranges and have three-pointer presentations; the military versions of these altimeters are described in references 1 and 2. The precision instruments are built with 50,000- and 80,000-foot ranges and have three-pointer, drum-pointer, and counter-pointer presentations; the military versions of these altimeters are described in references 3 to 5.

In the test procedures that govern the acceptance testing of these instruments, three properties of the aneroid-linkage mechanism are assessed, namely, scale error, hysteresis, and aftereffect. As prescribed in references 1 to 5, these errors are determined from a single calibration of the instrument with measurements at 20 or more selected pressures as the altitude indication is increased to its maximum range and at three test pressures as the indication is returned to zero.

Three additional properties of the aneroid-linkage mechanism which are of interest from an operational standpoint are repeatability, stability, and drift. Although none of the test procedures in references 1 to 5 require tests for any of these properties, the importance of stability is recognized in the latest specification for a precision-type altimeter (ref. 6, which prescribes tolerances for stability following a series of endurance tests and a cycling test consisting of 2,000 programed pressure cycles to an altitude of 50,000 feet). The importance of drift is recognized in a proposed test procedure for sensitive altimeters (ref. 7, which specifies drift tolerances following 4- and 6-hour tests at altitudes of 30,000 and 50,000 feet, depending on the range of the instrument).

An investigation to determine the repeatability and drift of an early model of a sensitive-type altimeter was conducted in 1934 (ref. 8). More recently (1958) another investigation was conducted to determine the drift and aftereffect of two types of sensitive altimeters and of one type of precision altimeter (ref. 9). In these tests the drift and aftereffect were measured for simulated flights of 4- and 6-hour duration at an altitude of 30,000 feet.

In order to provide additional information on some of the aneroid-linkage deflection characteristics of the type of altimeters in operational use at the present time, the National Aeronautics and Space Administration has conducted a series of tests with 28 altimeters representing two types of sensitive altimeters and one type of precision altimeter. In one series of tests the repeatability has been determined throughout the full range of each type instrument; in another series drift has been measured during periods of 1 hour at various altitudes; and in a third series drift and aftereffect have been determined for a variety of simulated flights representative of some typical civil and military operations. No tests for stability were included in the present investigation.

DEFINITIONS

Scale error: The difference between the height indicated by an altimeter at a given pressure and the height in the standard atmosphere at the same pressure; the pressure-height relation used for the measurement of scale errors in the present investigation is that given in references 1 and 3.

Repeatability: A measure of the constancy of the scale errors as determined by successive calibrations conducted over a short period of time; in this report the repeatability errors are defined as the difference between the scale errors at a given pressure as measured in calibrations conducted on 2 successive days.

Stability: A measure of the constancy of the scale errors as determined by calibrations conducted over a relatively long period of time or following the application of a large number of pressure cycles.

Hysteresis: The difference in altimeter readings as determined at a given pressure during the increasing and decreasing pressure cycle.

Aftereffect: The hysteresis, at sea-level pressure, at the completion of a pressure cycle.

Drift: The change in altimeter reading with time when the instrument is subjected to a constant pressure.

Recovery: The drift, at sea-level pressure, which occurs at the completion of a pressure cycle; the direction of this drift is toward the initial scale-error value.

TEST INSTRUMENTS AND CALIBRATION APPARATUS

Test Instruments

The altimeters tested during the present investigation included two sensitive types (Air Force type C-12 and C-13) and one precision type (Air Force type MA-1). Ten instruments of each of the three types were procured for the test program. Inspection labels attached to the C-13 altimeters indicated that these instruments had been overhauled by an instrument repair facility 6 years prior to their receipt at the Langley Research Center; similarly, labels attached to the C-12 altimeters indicated that these instruments had been overhauled by another instrument repair facility 2 years prior to their receipt. The MA-1 altimeters had been calibrated by the manufacturer $1\frac{1}{2}$ years prior to their receipt; and, since they were received with the manufacturer's original scale-error correction cards attached, they appeared to have been unused during that time. On receipt of the instruments it was found that the pointers of two of the C-12 instruments were out of adjustment with the barometric dial by a considerable amount; therefore, only eight of these instruments were tested in the present investigation.

Calibration Apparatus

For all of the tests the altimeters were mounted in units of two on platforms set on sponge-rubber mats (figs. 1 and 2). Each platform was equipped with a 60-cycle vibrator that produced an amplitude of vibration equivalent to about 0.2g.

Since the primary test requirement for repeatability tests is a high order of precision in setting and measuring the height of the mercury column whereas a means of maintaining a constant pressure over long periods of time is the primary requirement for drift tests, different types of barometric test equipment were used in the present investigation for the repeatability and the drift-aftereffect tests.

Repeatability tests.- For the repeatability tests, the calibration standard was a precision barometer with an automatic system for measuring the height of the mercury column (fig. 1). With this equipment the height of the mercury column is adjusted by manually applying pressure or suction to the system; continuous measurements of the height of the column are provided by a photocell scanner that detects displacements of the mercury meniscus and moves along a vertical precision screw whenever signals from the scanner cause a servomotor to rotate the screw. The revolutions of the screw, a measure of the vertical position of the scanner, are registered on a digital counter. In this barometer a fixed vacuum above the mercury column was established by evacuating and sealing the barometric tube. The temperature of the mercury column was maintained constant, within close limits, by thermostatic control of the cabinet in which the barometer and the height-measuring mechanism are encased. The smallest unit on the digital counter was 0.1 pound per square foot. From four calibrations of the barometer by means of an air piston gage, it was found that the repeatability of the barometer readings was also within 0.1 pound per square foot. Altitude increments corresponding to this pressure increment for an altitude range up to 80,000 feet are given in figure 3.

Drift and aftereffect tests.- For the tests of drift and aftereffect the calibration standard was a precision barometer with an automatic mechanism for maintaining the pressure in the system at a selected value (fig. 2). This mechanism consists of (1) a photocell scanner that detects deviations of the mercury meniscus from the preset height of the scanner, and (2) a servomechanized pressure controller that applies increments of pressure or suction to maintain the pressure of the system to that corresponding to the setting of the photocell scanner. In this barometer the vacuum above the mercury column was maintained by continuous pumping and the degree of vacuum achieved was measured with a vacuum gage. Corrections for deviations of the temperature of the mercury column from the temperature at which the barometer was calibrated were applied by manual setting of an automatic temperature compensator with which this type instrument is equipped. The scale of this barometer was graduated in units of inches of mercury, and the accuracy with which the scanner could be set to a selected pressure was about 0.001 inch of mercury. From tests of the sensitivity of the pressure controller by means of an air piston gage, it was found that the accuracy with which the controller could maintain a preset pressure was about 0.001 inch of mercury for altitudes up to about 50,000 feet. Altitude increments corresponding to a pressure increment of 0.001 inch of mercury are given in figure 3 for altitudes up to 80,000 feet.

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At an altitude of 70,000 feet at which one of the drift tests was conducted, it was found that the pressure controller could not maintain the pressure of the system to better than about 0.003 inch of mercury, a pressure variation corresponding to an altitude variation of 48 feet at this altitude. As a means of minimizing this error, the barometer with the digital readout was inserted in the system and was used to measure the pressure deviations from the preset value at 70,000 feet. The accuracy of the measurements from this test was, therefore, on the order of 0.1 pound per square foot.

TEST PROGRAM AND CALIBRATION PROCEDURES

In the present investigation the repeatability of each of the three types of altimeters was determined from scale-error calibrations of the instruments on two successive days. The drift characteristics of the instruments were determined from 1-hour drift tests at two altitudes of operational interest for each type altimeter; drift and aftereffect were measured for simulated flight profiles representative of some civil and military operations.

For all of these tests the barometric dials of the instruments were set at 29.92 inches of mercury. The ambient temperature at which the tests were conducted was between 23° C and 25° C. Prior to each test the instruments were at rest for a period of at least 12 hours. For all of the tests the altimeter indications were read to the nearest 5-foot increment; that is, a reading accuracy of ±2.5 feet.

Repeatability Tests

For the repeatability tests, ten C-13, eight C-12, and ten MA-1 altimeters were calibrated through the full altitude range of the respective types. All instruments of a given type were calibrated simultaneously. The calibrations were performed at altitude test points selected from the standard-calibration test procedures in references 1 and 3; measurements were made at each test point for both increasing and decreasing altitude. The rate of altitude change between the test points was about 3,000 feet per minute and attempts were made to bring the mercury column to each test point without overshoot. After the column had been brought to the desired height, the barometer was tapped to relieve any sticking of the mercury to glass. For cases where the column height differed from that corresponding to the test point, corrections were applied to the altimeter indication. Following a 1-minute stabilization period at each test point, the instruments were vibrated about 5 seconds and the altimeter indications recorded; the pressure was then immediately changed toward the succeeding test point.

Drift and Aftereffect Tests

Drift during 1-hour period.- In the 1-hour drift tests, six of the C-13 altimeters were tested at 20,000 and 30,000 feet, six of the C-12 altimeters were tested at 30,000 and 40,000 feet, and six of the MA-1 altimeters were tested at 40,000 and 70,000 feet. In order to provide directly comparable data for the different instrument types, the C-13 and C-12 instruments were tested concurrently at 30,000 feet, and the C-12 and MA-1 instruments were tested concurrently at 40,000 feet. In the tests at 20,000, 30,000, and 40,000 feet the altimeter indications were recorded at 1, 5, 10, 15, 30, 45, and 60 minutes after the pressure stabilized at the test altitude. Because of the greater uncertainty in the stability of the system pressure at 70,000 feet, readings at this altitude were made at approximately 1-minute time intervals up to 15 minutes and at 5-minute intervals between 15 and 60 minutes. All of the readings were made only when the system pressure was stabilized and the instruments were vibrated 5 seconds before the altimeter indications were recorded. For all of the tests the rate of climb to the test altitude was about 3,000 feet per minute.

Drift and aftereffect during simulated flights.- Six C-13 and six C-12 altimeters were tested concurrently for simulated flight profiles at altitudes of 10,000 and 30,000 feet. In the first of these tests the altimeters were brought to 10,000 feet at a rate of climb of about 2,000 feet per minute and the drift measured between 1 and 10 minutes following pressure stabilization at the test altitude. The instruments were then returned to sea-level pressure at a rate of descent of about 2,000 feet per minute and the aftereffect and recovery determined between 1 and 10 minutes following pressure stabilization at sea-level pressure. This cycle was repeated until four drift and aftereffect measurements had been obtained.

In the second test the altimeters were brought to 30,000 feet at a rate of climb of about 3,000 feet per minute and the drift was measured between 1 minute and 6 hours following pressure stabilization at the test altitude. The instruments were then returned to sea-level pressure at a rate of descent of about 3,000 feet per minute and the aftereffect measured at 1 minute after the pressure had stabilized at this pressure.

For two other simulated flight profiles, the drift and aftereffect of six MA-1 altimeters were determined for a simulated 6-hour flight at 40,000 feet and a 1-hour flight at 50,000 feet. The rate of climb and descent for the 40,000-foot test was about 3,000 feet per minute; for the 50,000-foot test the rate of climb was about 25,000 feet per minute and the rate of descent was about 5,000 feet per minute.

For all of the drift tests the pressure above the mercury column and the temperature of the barometer were measured each time the altimeter indications were recorded. Whenever the pressure or temperature varied from their values at the beginning of the test, corrections were applied to the altimeter readings. For the 1-hour drift test at 70,000 feet, corrections were also applied for variations in the system pressure, which, in this test, was found to vary by a maximum of ±0.2 pound per square foot.

RESULTS AND DISCUSSION

The results of the tests with the three types of altimeters are presented in figures 4 to 22. Figures 4 to 6 present the first of the two scale-error calibrations from which the repeatability of the instruments was determined. The repeatability measurements are then presented in figures 7 to 10. The drift characteristics of each of the three types of altimeter as determined during a 1-hour period at two altitudes of operational interest for each type instrument are presented in figures 11 to 16. Drift and aftereffect of the sensitive altimeters as measured during simulated flights at 10,000 and 30,000 feet and of the precision altimeters as measured during simulated flights at 40,000 and 50,000 feet are presented in figures 17 to 22.

Scale-Error Calibrations

The first of the two scale-error calibrations determined for the C-13, C-12, and MA-1 altimeters are presented in figures 4, 5, and 6, respectively. Although the primary purpose of the two calibrations was to obtain a measure of the repeatability of the instruments, it may also be of interest to compare the magnitudes of the scale errors, the hysteresis, and the aftereffect as determined from the first calibration with the allowable tolerances for these errors. The scale-error tolerances of the three types of altimeters (from refs. 1 and 3) are presented in figure 23; these tolerances apply only to increasing altitude portion of the calibration. The tolerances for the hysteresis and aftereffect for the three instruments (refs. 1 and 3), are given in the following table:

Altimeter	Hysteresis tolerance, ft, at test altitude of:				Aftereffect tolerance, ft, at zero altitude
	16,000	18,000	20,000	25,000	
C-13	70	70			50
C-12			150	150	60
MA-1			100	100	50

A comparison of the scale errors on figures 4 to 6 with the tolerances in figure 23 shows that all of the instruments were within tolerance with the exception of the C-12 altimeters numbers 5 and 6, which exceeded the 50-foot tolerance at zero altitude.

For each of the three types of instrument, the hysteresis and aftereffect as measured by the calibrations on figures 4 to 6 at the test altitudes listed in the previous table are summarized in the following table. In this summary the minimum, maximum, and average values of the hysteresis at the test altitudes (16,000 and 18,000 feet for the C-13 altimeter and 20,000 and 25,000 feet for the C-12 and MA-1 altimeters) and the minimum, maximum, and average aftereffect values are compared with the tolerances for these errors.

Altimeter	Hysteresis, ft			
	Minimum	Maximum	Average	Tolerance
C-13	60	110	87	70
C-12	80	160	112	150
MA-1	10	45	25	100

Altimeter	Aftereffect, ft			
	Minimum	Maximum	Average	Tolerance
C-13	25	55	33	50
C-12	25	60	41	60
MA-1	5	20	10	50

From a comparison of these values it is apparent that the hysteresis and aftereffect of the MA-1 altimeters are appreciably smaller than those of the C-12 and C-13 altimeters; in addition, the errors of the MA-1 instrument are a smaller percent of the allowable tolerances than is the case for the two sensitive altimeters.

Repeatability

The repeatability of ten C-13, eight C-12, and ten MA-1 altimeters, as determined from the calibrations in figures 4 to 6 and a second series of calibrations performed the day after the first series was conducted, is presented on figures 7 to 9. In these figures the amounts by which the scale errors of the second calibration differ from those of the first calibration are given for each of the test altitudes for both the increasing and decreasing altitude cycle.

In figure 10 the scale-error differences of all of the instruments of a given type have been combined to provide an indication of the repeatability of each type of altimeter. In this figure the extreme and average values of the scale errors determined at each test point (for both increasing and decreasing altitude) are plotted as a function of altitude. On the basis of the extreme values in this figure, the repeatability of the C-13 instrument is within ±20 feet throughout the altitude range up to 35,000 feet. With the exception of the 30-foot value at zero altitude, the repeatability of the C-12 type is within ±20 feet up to 35,000 feet and within about ±40 feet in the altitude range between 35,000 feet and 50,000 feet. For the MA-1 altimeter, the repeatability is within ±10 feet up to 25,000 feet, and ±20 feet up to 50,000 feet; above this range the values increase to a maximum of about 150 feet at 80,000 feet. It will be noted that the repeatability at 70,000 and 80,000 feet is generally positive, with an average value for the ten altimeters of 75 feet at 80,000 feet. It is possible that some part of this trend is due to barometer errors which, assuming a barometer repeatability of 0.1 pound per square foot, corresponds to an altitude error of 37 feet at 80,000 feet. A barometer error of this magnitude would account for one-half of the 75-foot bias.

Drift During 1-Hour Period at Various Altitudes

The drift errors of six C-13 altimeters at 20,000 and 30,000 feet, six C-12 altimeters at 30,000 and 40,000 feet, and six MA-1 altimeters at 40,000 and 70,000 feet as measured during a 1-hour period at each altitude are presented in figures 11 to 16. Because of the relatively large scatter of the data from the test of the MA-1 altimeters at 70,000 feet (fig. 16), the data points at this altitude have been faired on the basis of the general trend of the drift of the MA-1 instruments at 40,000 feet (fig. 15). It may be noted that the scatter of the data in the 70,000-foot test is within the repeatability of the barometer used to measure the pressure fluctuations in this test (0.1 pound per square foot or 22 feet at 70,000 feet).

The curves in figures 11 to 16 show that the greater part of the total drift occurs during the period immediately following the 1-minute stabilization period at the test altitudes. For many of the instruments, particularly the MA-1 altimeters, the drift would appear to have reached a maximum value within the 1-hour period. As will be shown later, however, the drift of most of the altimeters at the end of 6 hours was somewhat greater than the values at the end of the 1-hour test.

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The average of the drift values at the end of the 1-hour period for the C-13 type altimeters is 36 feet at 20,000 feet and 43 feet at 30,000 feet. For the C-12 altimeters these average total-drift values are 23 feet at 30,000 feet and 44 feet at 40,000 feet; for the MA-1 instruments the average values are 8 feet at 40,000 feet and 13 feet at 70,000 feet. These values indicate that for each of the three types of instruments, the drift errors increase with altitude. The values also show that for a given altitude, the drift of the C-12 instruments is smaller than that of the C-13 instruments (23 feet as compared with 43 feet at 30,000 feet), and the drift of the MA-1 altimeters is smaller than that of the C-12 instruments (8 feet as compared with 44 feet at 40,000 feet).

Drift and Aftereffect Measured in Simulated Flights

<u>Sensitive altimeters - four 10-minute flights at 10,000 feet</u>.- The drift and aftereffect of six C-13 and six C-12 altimeters measured during four simulated 10-minute flights at an altitude of 10,000 feet are shown on figures 17 and 18. These figures show that, although the drift for any single 10-minute period at 10,000 feet is small (10 feet in the worst case), the drift at the end of the fourth period is generally larger than that at the end of the first period. For the C-13 altimeters the average overall drift (the difference between the altimeter indications at the beginning of the first period and the end of the fourth) is 16 feet; for the C-12 instruments the average overall drift is 17 feet.

For both types of altimeters the incremental aftereffect is generally greatest at the end of the first flight with relatively smaller increases on the succeeding flights. The average aftereffect for the six C-13 altimeters is 18 feet at the end of the first flight and 33 feet at the end of the fourth; for the C-12 instruments the average values are 33 feet at the end of the first flight and 51 feet at the end of the fourth. The average values of the aftereffect at the end of the fourth flight are of the same order as the average values determined in the scale-error calibrations of these same instruments (31 feet for the C-13 instruments, and 46 feet for the C-12 instruments).

Sensitive-type altimeters - 6-hour flight at 30,000 feet.- The drift and aftereffect of six C-13 and six C-12 altimeters resulting from a simulated 6-hour flight at 30,000 feet are presented in figures 19 and 20.

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1 The results of these tests showed that the drift of the C-13
5 altimeters ranged from 30 to 75 feet, while that for the C-12 altimeters
8 ranged from 20 to 35 feet; the average value for the C-13 instruments
0 was 58 feet, while that for the C-12 instruments was 28 feet. These
average values are somewhat higher than those obtained with the same instruments in the 1-hour drift tests at 30,000 feet (43 feet for the C-13 altimeters, and 23 feet for the C-12 altimeters). Both the 1-hour and 6-hour tests show that the drift of the C-12 instruments is smaller than that of the C-13 instruments.

The aftereffect errors of the C-13 and C-12 altimeters range from 45 to 70 feet for the C-13 instruments and from 40 to 65 feet for the C-12 instruments. The average of these errors (58 feet for the six C-13 altimeters and 55 feet for the six C-12 altimeters) is larger than the average of the aftereffect errors of these six instruments as measured in the scale-error calibrations (31 feet for the C-13 altimeters and 45 feet for the C-12 altimeters). The differences in these values are a measure of the influence of drift at altitude on the magnitude of the aftereffect at sea-level pressure.

Precision altimeters - 6-hour flight at 40,000 feet and 1-hour flight at 50,000 feet.- The drift and aftereffect of six MA-1 altimeters resulting from a 6-hour flight at 40,000 feet and a 1-hour flight at 50,000 feet are presented in figures 21 and 22.

For the 6-hour test at 40,000 feet, the drift errors of the six altimeters range from 10 to 15 feet. As in the case of the C-13 and C-12 altimeters, the average value for the 6-hour test (13 feet) is slightly greater than that for the 1-hour drift test at 40,000 feet (8 feet).

For the simulated 1-hour flight at 50,000 feet the drift errors of the six instruments range from 10 to 35 feet. Although the average of these errors (25 feet) would be expected, because of the higher altitude, to be larger than the 8-foot value obtained in the 1-hour test at 40,000 feet, the fact that the error is on the order of three times the value obtained at 40,000 feet is undoubtedly due to the much higher rate of climb preceding the drift measurements at 50,000 feet. It would appear, therefore, that the drift of an altimeter increases with the rate of climb as well as altitude (as was indicated by the 1-hour drift tests at various altitudes).

The aftereffect of the six altimeters was 0 to 5 feet for the 6-hour test at 40,000 feet and 5 to 10 feet for the 1-hour test at 50,000 feet. The higher values for the 50,000-foot test are in agreement with the higher drift errors developed in this test. The average of these values (4 feet for the test at 40,000 feet, and 8 feet for the test at 50,000 feet) are of the same order as the average value (7 feet) determined for these six instruments in the scale-error calibration.

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From a comparison of the results of both the 1-hour drift tests and the simulated flight profiles, it is apparent that the drift and aftereffect of the MA-1 altimeters are in all cases appreciably lower than those of the C-13 and C-12 altimeters.

In simulated 6-hour flights at 30,000 feet reported in reference 9, it was found that the average of the drift values of three sensitive altimeters was 70 feet and for two precision altimeters the drift was on the order of 5 feet. The aftereffect measured in these tests was 25 feet for the sensitive instruments and 5 feet for the precision instruments. Although these values differ somewhat from those measured in the present investigation, the results of both series of tests are in agreement in showing the drift and aftereffect of the MA-1 altimeters to be considerably smaller than those of the C-12 and C-13 altimeters.

CONCLUSIONS

From the results of a series of laboratory tests of 18 sensitive altimeters (Air Force type C-12 and C-13) and of 10 precision altimeters (Air Force type MA-1), it has been concluded that:

1. The repeatability of the C-13 altimeter was within ±20 feet throughout its range of 35,000 feet. The repeatability of the C-12 type was within about ±20 feet to 35,000 feet and about ±40 feet to 50,000 feet. The repeatability of the MA-1 altimeter was within ±10 feet to 25,000 feet, ±20 feet to 50,000 feet; above this range the values increase to a maximum of about 150 feet at 80,000 feet.

2. The hysteresis and aftereffect of the MA-1 altimeters as determined from the scale error calibrations were considerably smaller than the values for the C-12 and C-13 altimeters. The values measured for

the MA-1 instruments were also a much smaller percent of the allowable tolerances than was the case of the C-12 and C-13 altimeters.

3. From 1-hour drift tests at various altitudes, the average total drift of the C-12 instruments was lower than that of the C-13 instruments, and the drift of the MA-1 instruments was considerably smaller than that of both the sensitive altimeters. These tests also showed the drift to increase with altitude.

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4. In tests simulating a variety of flight profiles, the drift and aftereffect developed during a number of successive flights of short duration tend to accumulate. In simulated flights of 6-hour duration the total drift for each of the three instrument types was somewhat greater than that measured in the 1-hour drift tests. Both the drift and aftereffect of the MA-1 instruments were appreciably smaller than the values obtained with the C-12 and C-13 instruments. The drift of the MA-1 altimeters was also found to increase with increasing rate of altitude change preceding the drift test.

Langley Research Center,
National Aeronautics and Space Administration,
Langley Field, Va., May 17, 1961.

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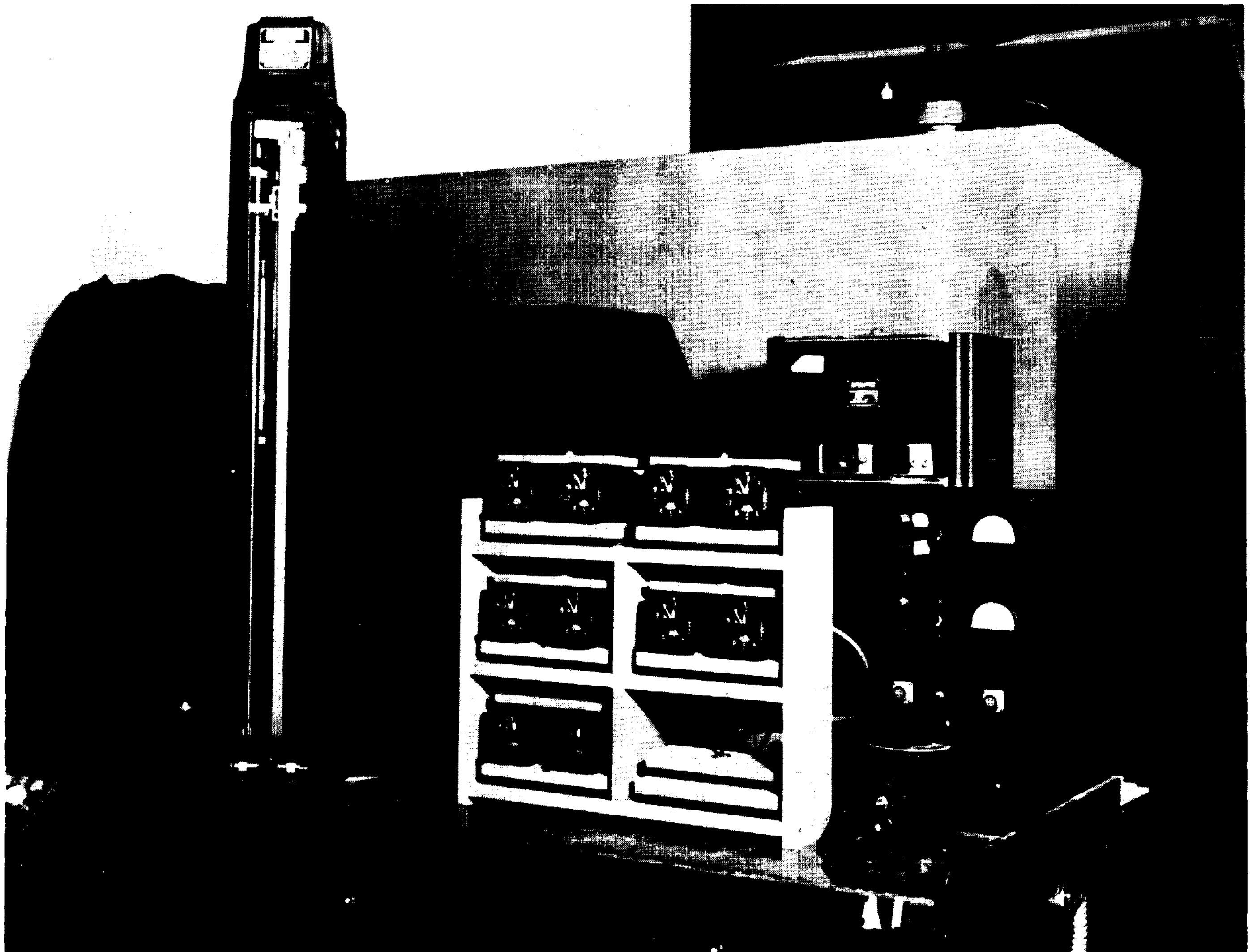

Figure 1.- Test apparatus used for repeatability tests. L-60-7941

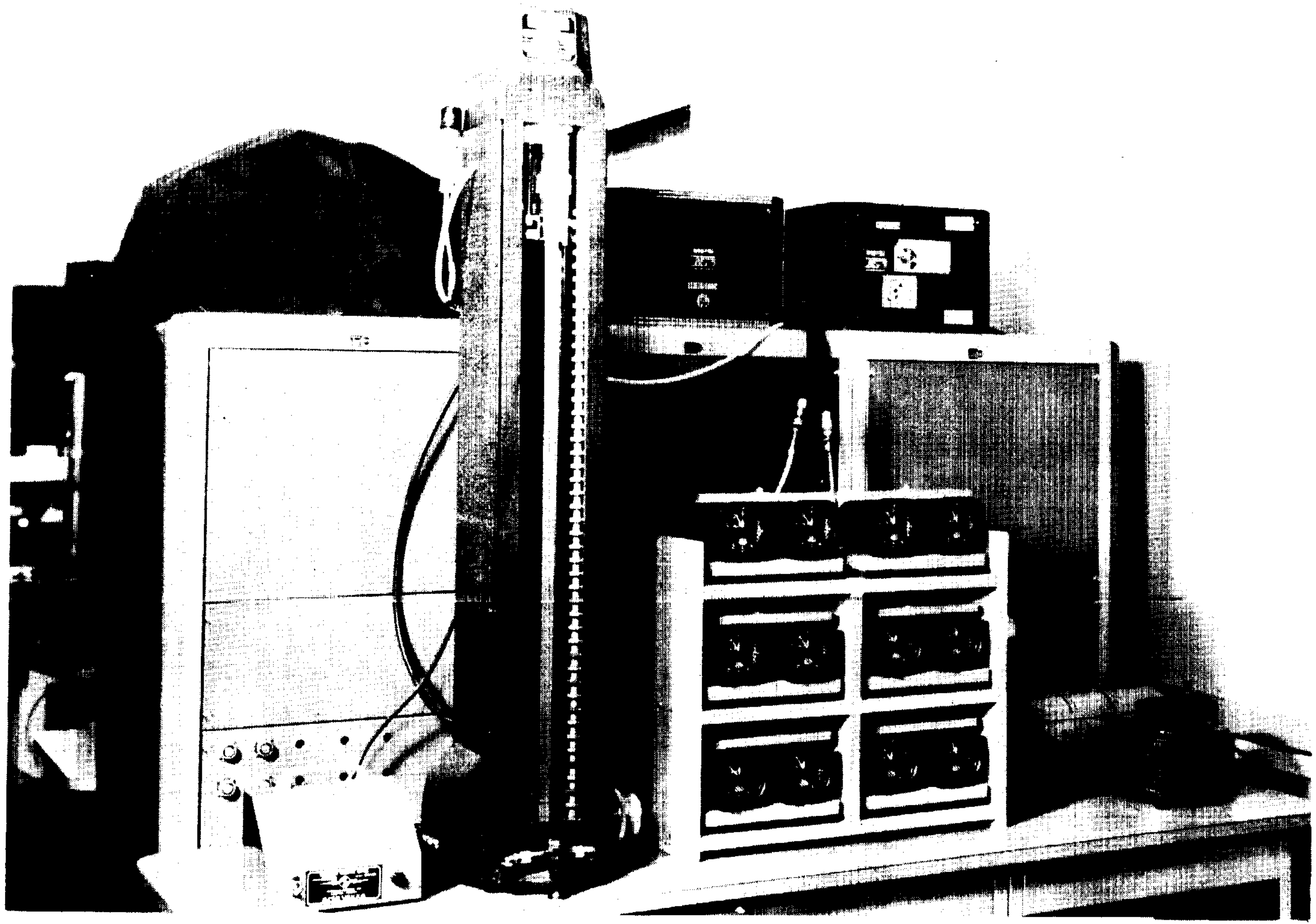

Figure 2.- Test apparatus used for drift and aftereffect tests. L-60-7940

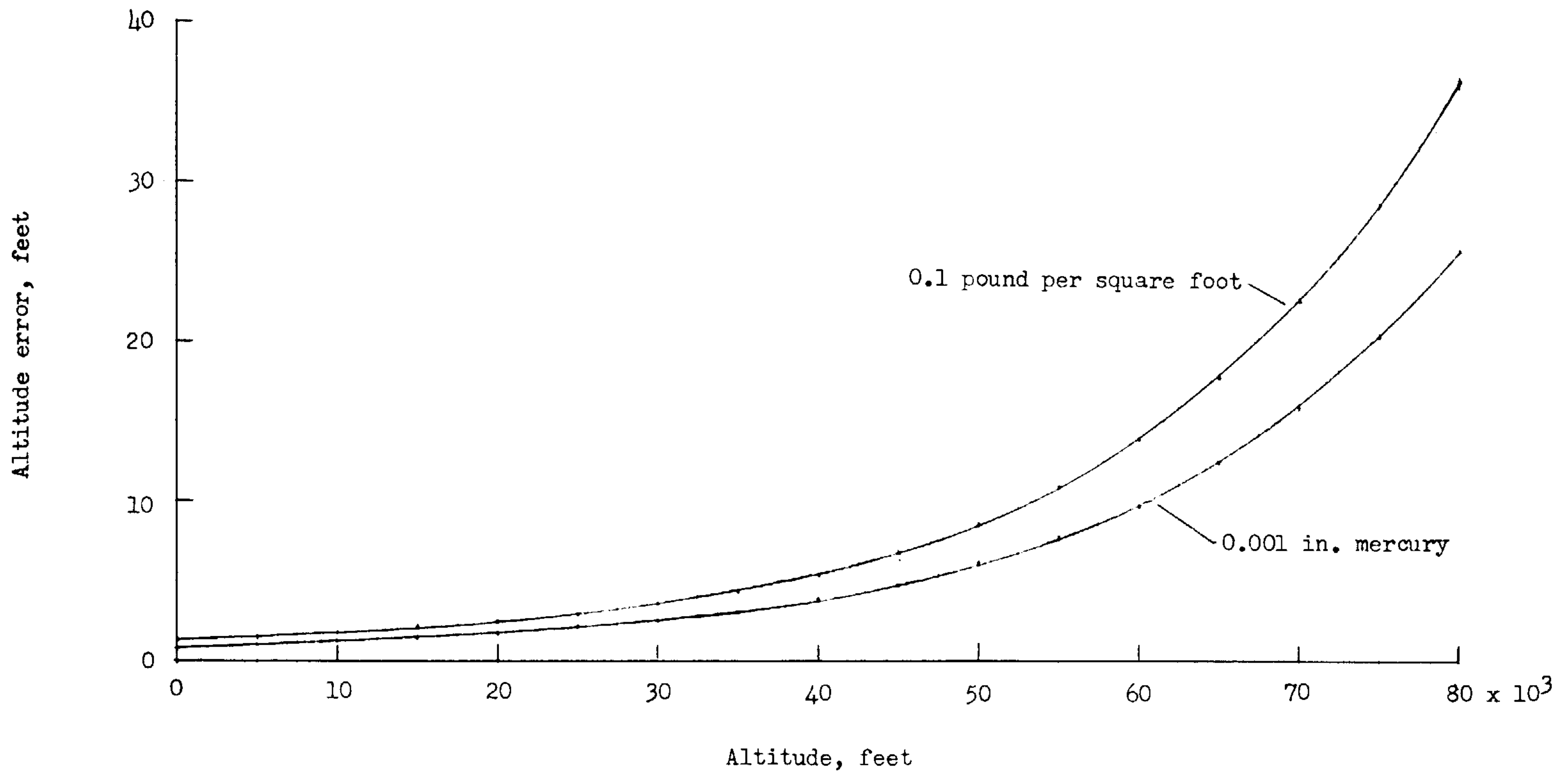

Figure 3.- Altitude errors equivalent to 0.1 pound per square foot and 0.001 inch of mercury.

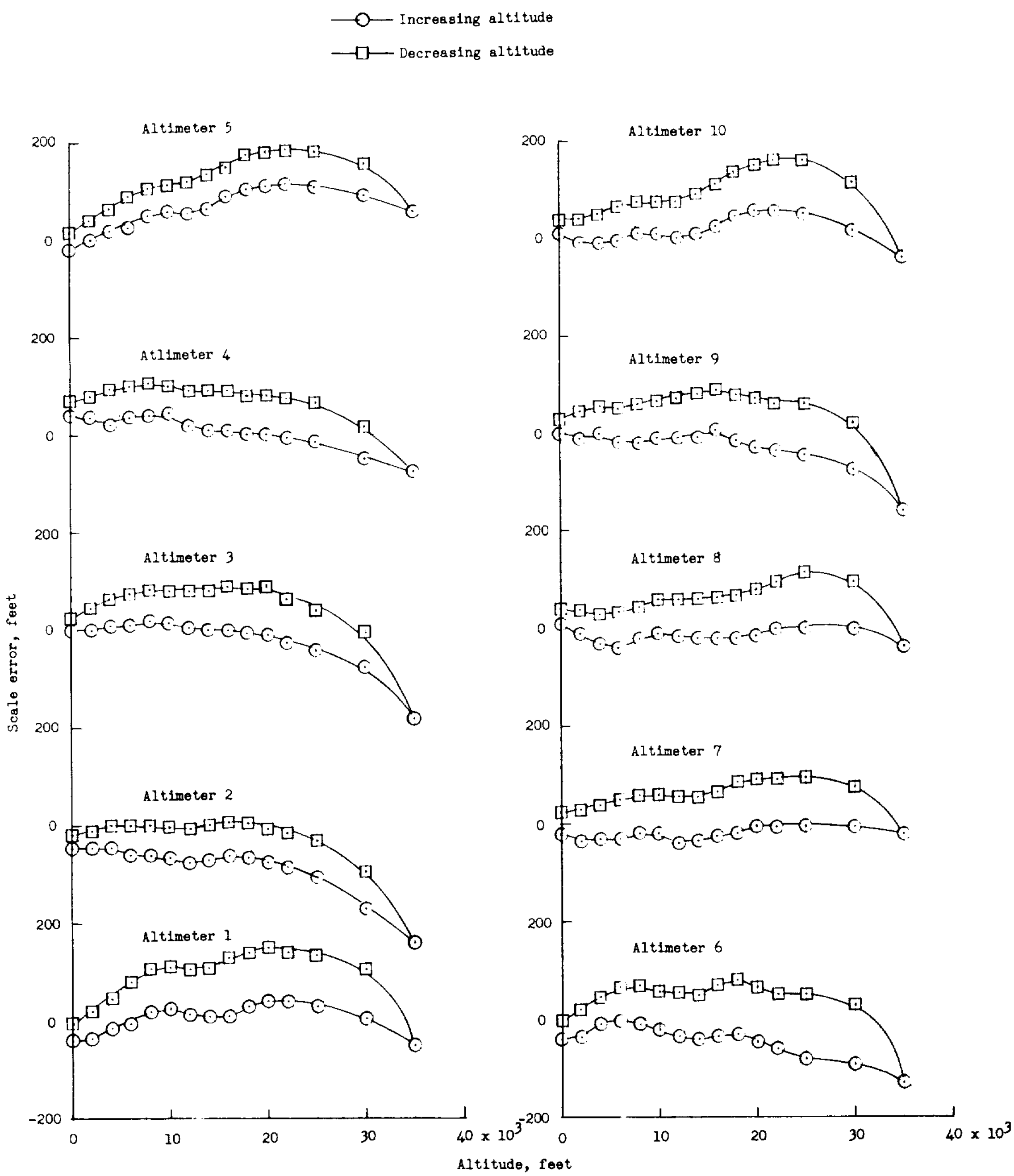

Figure 4.- Scale errors of ten C-13 altimeters.

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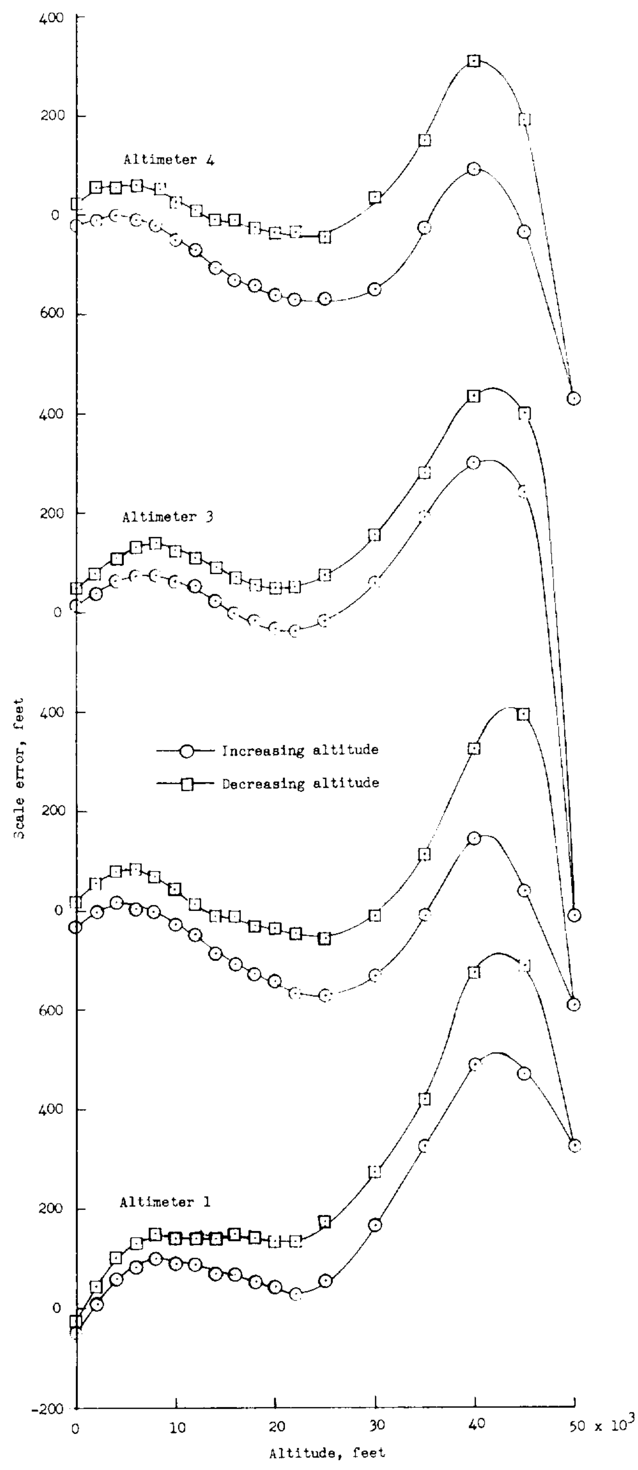

Figure 5.- Scale errors of eight C-12 altimeters.

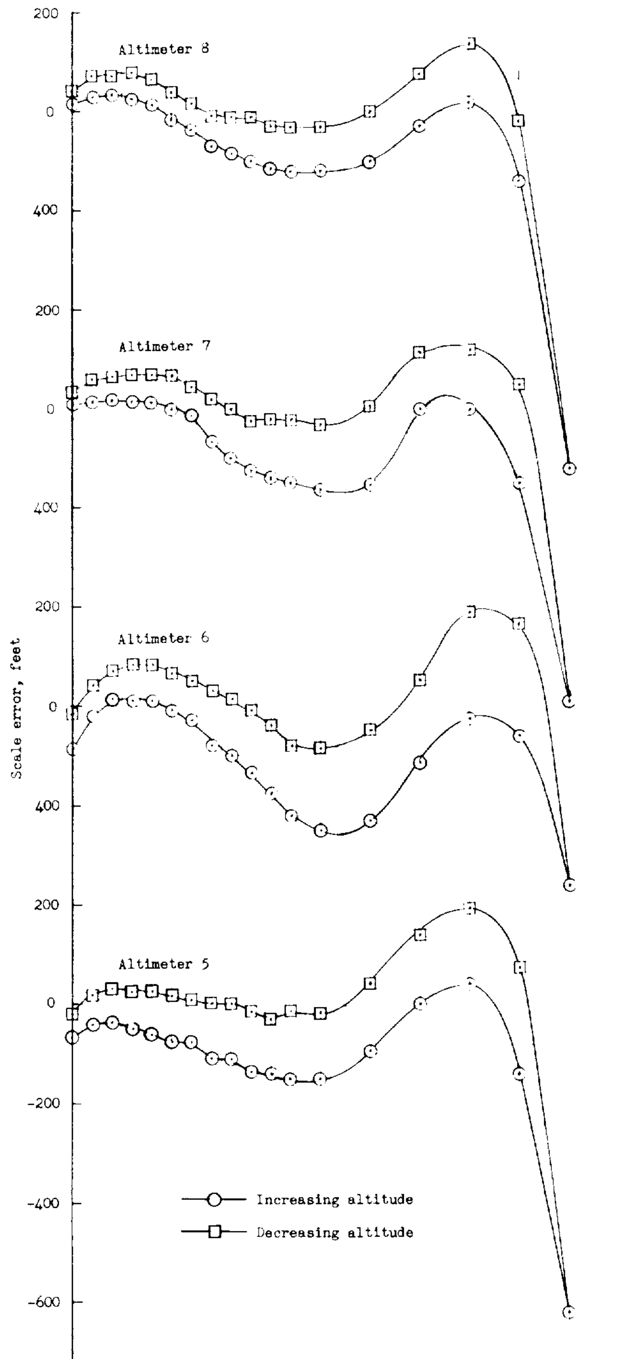

Figure 5.- Concluded.

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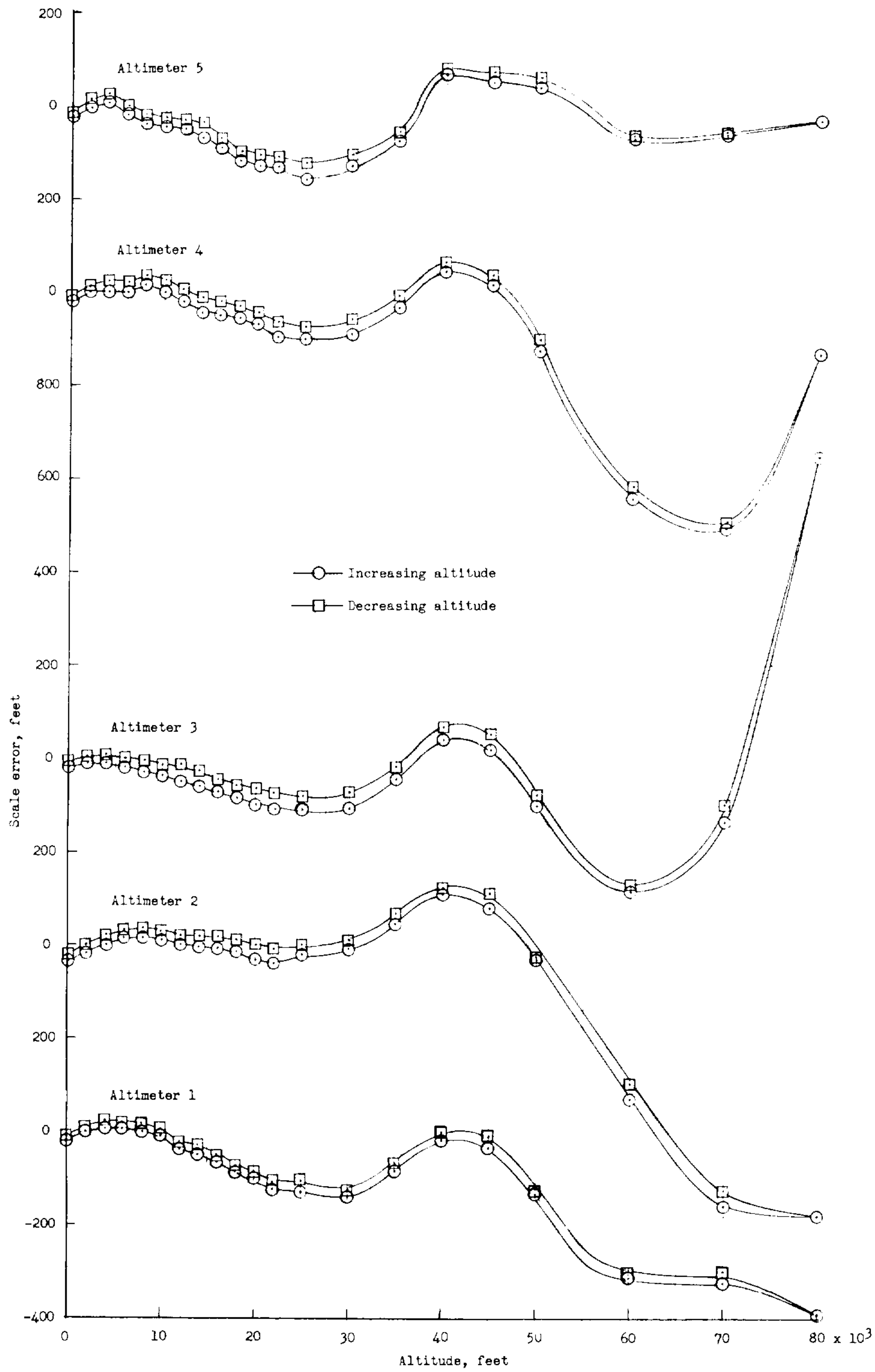

Figure 6.- Scale errors of ten MA-1 altimeters.

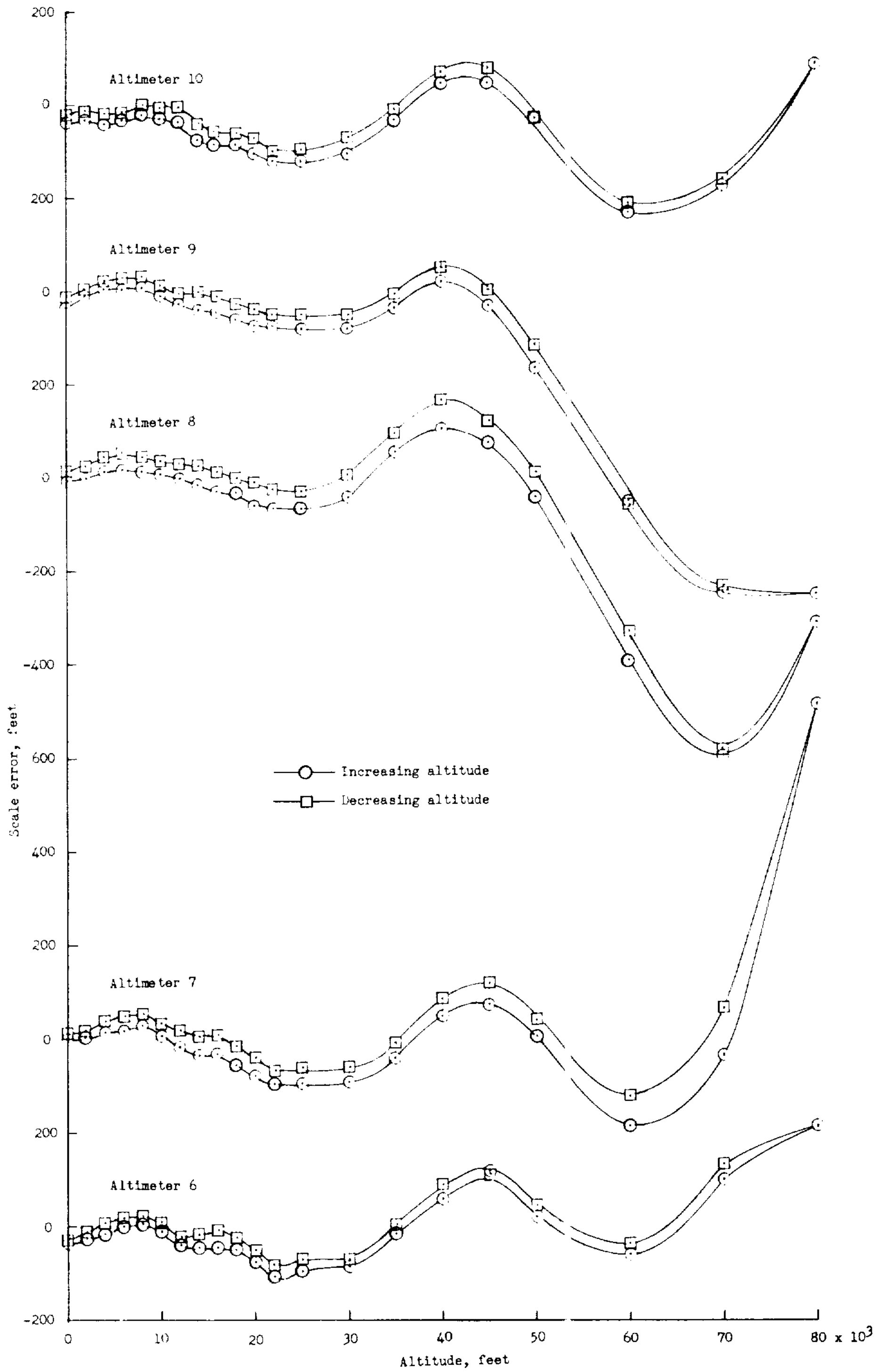

Figure 6.- Concluded.

L-1580

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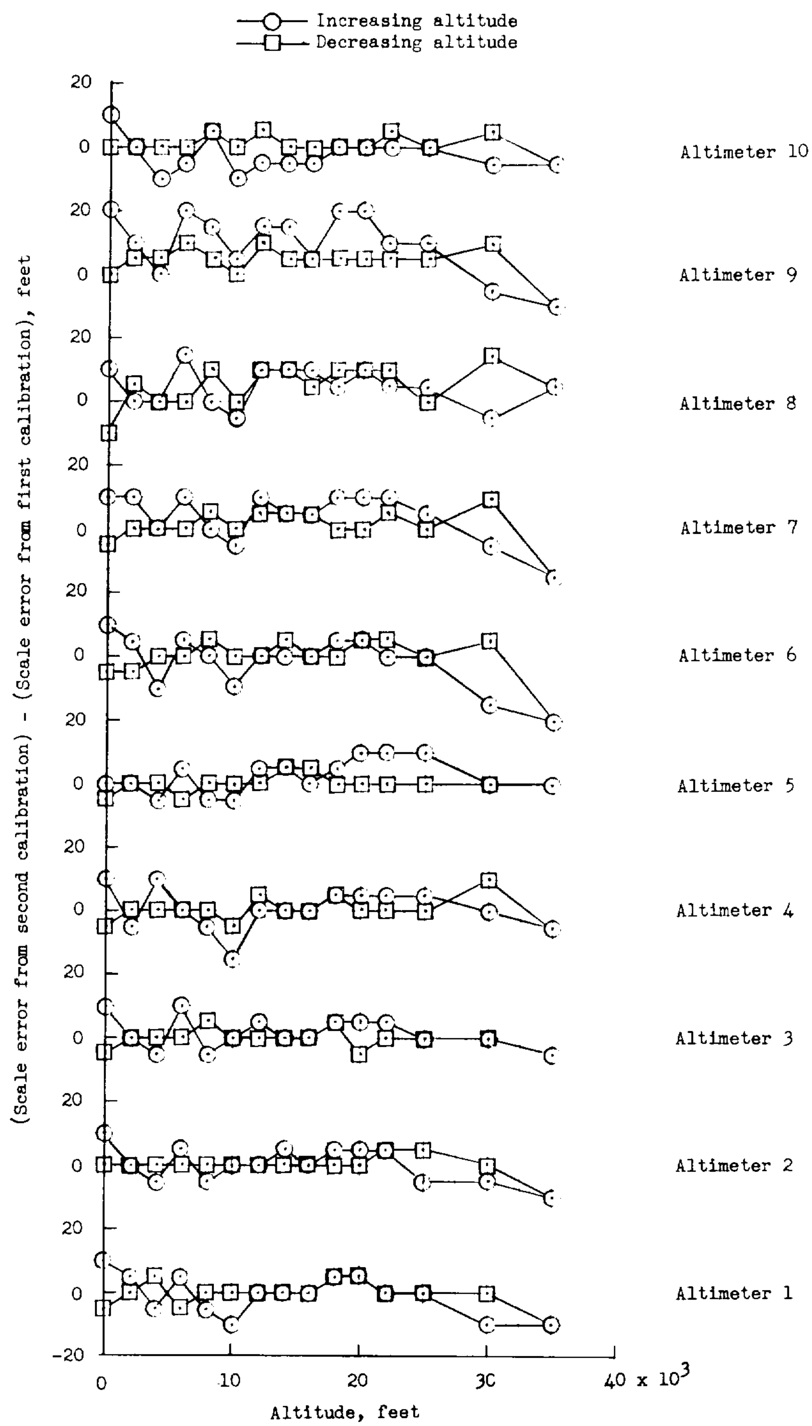

Figure 7.- Repeatability of the scale errors of ten C-13 altimeters as determined from two calibrations on successive days.

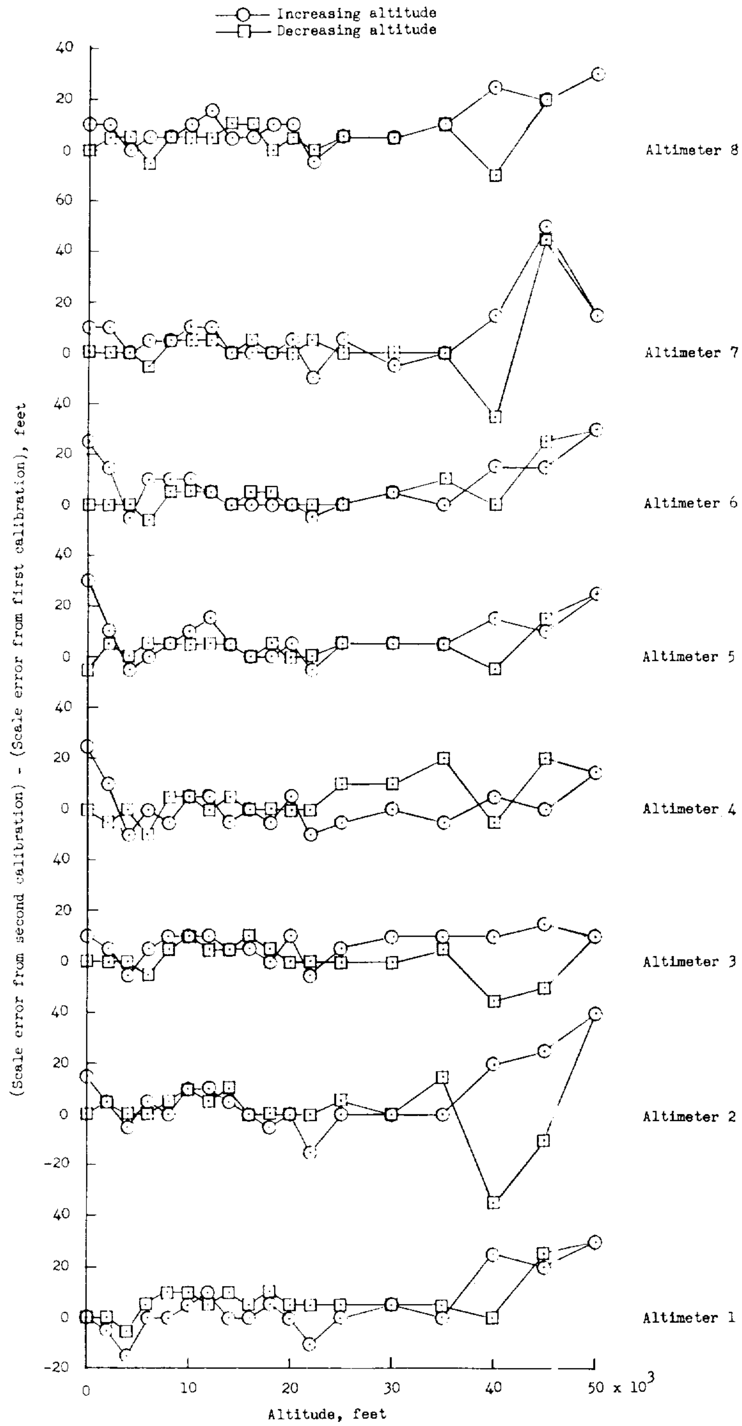

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Figure 8.- Repeatability of the scale errors of eight C-12 altimeters as determined from two calibrations on successive days.

L-1580

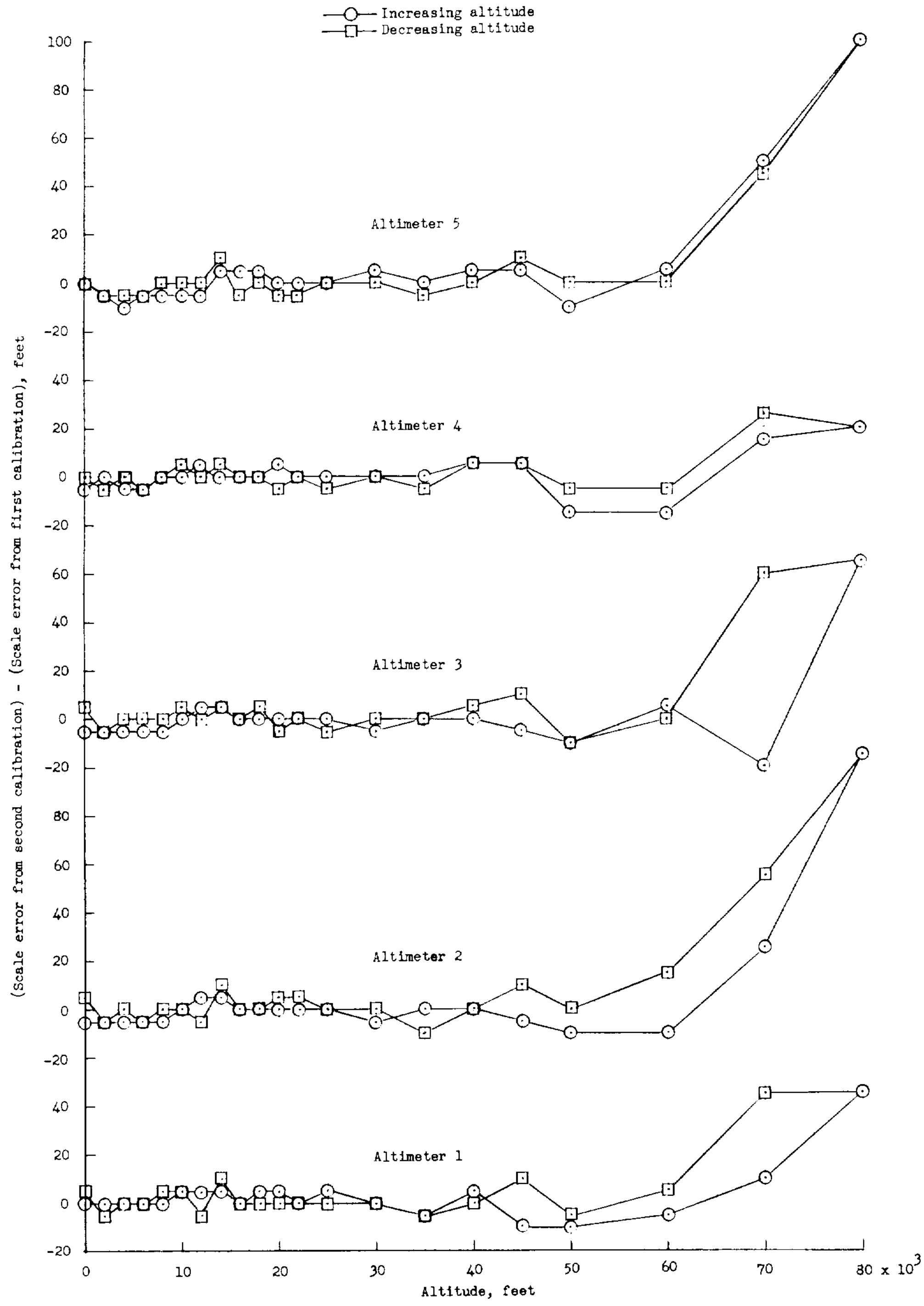

Figure 9.- Repeatability of the scale errors of ten MA-1 altimeters as determined from two calibrations on successive days.

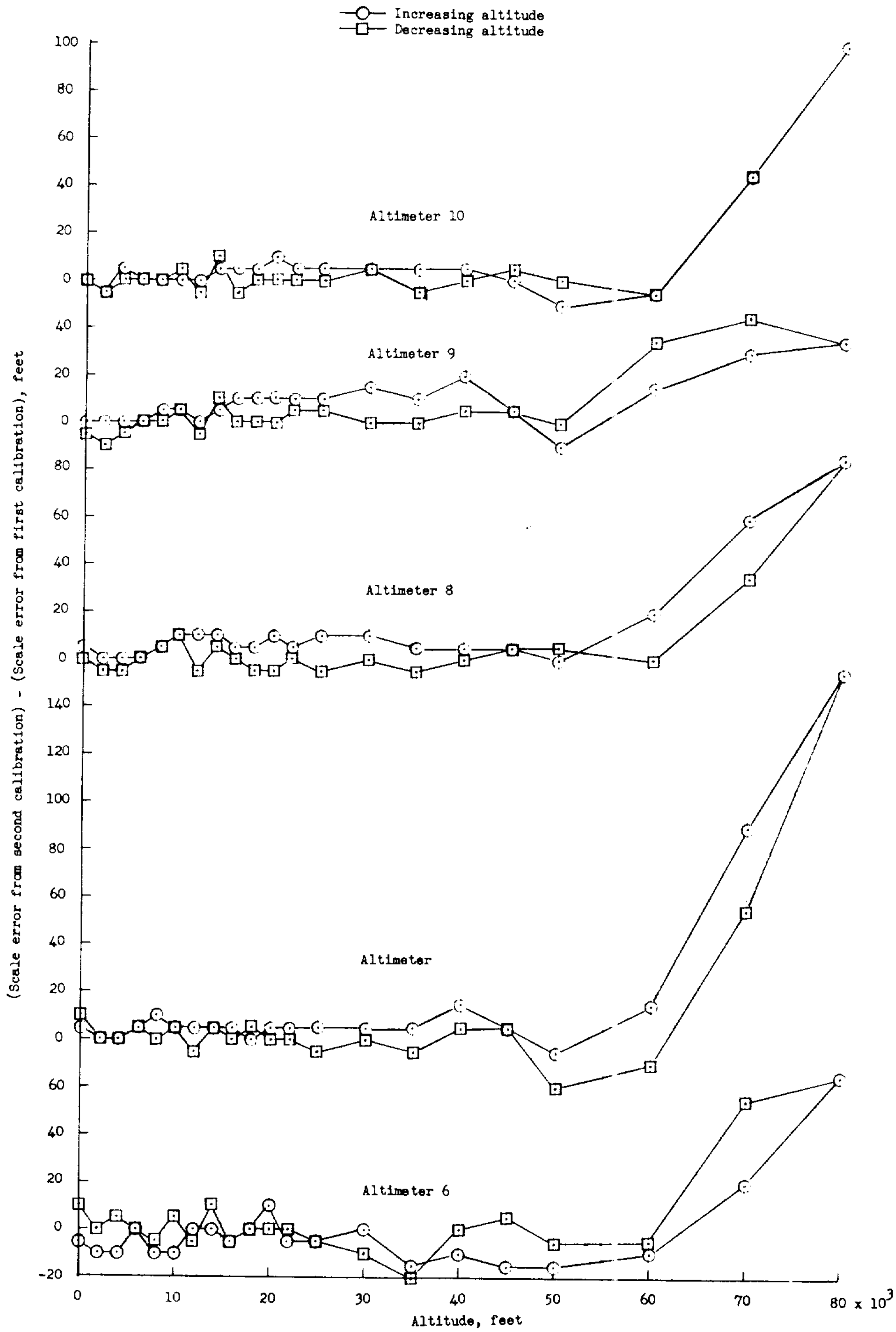

Figure 9.- Concluded.

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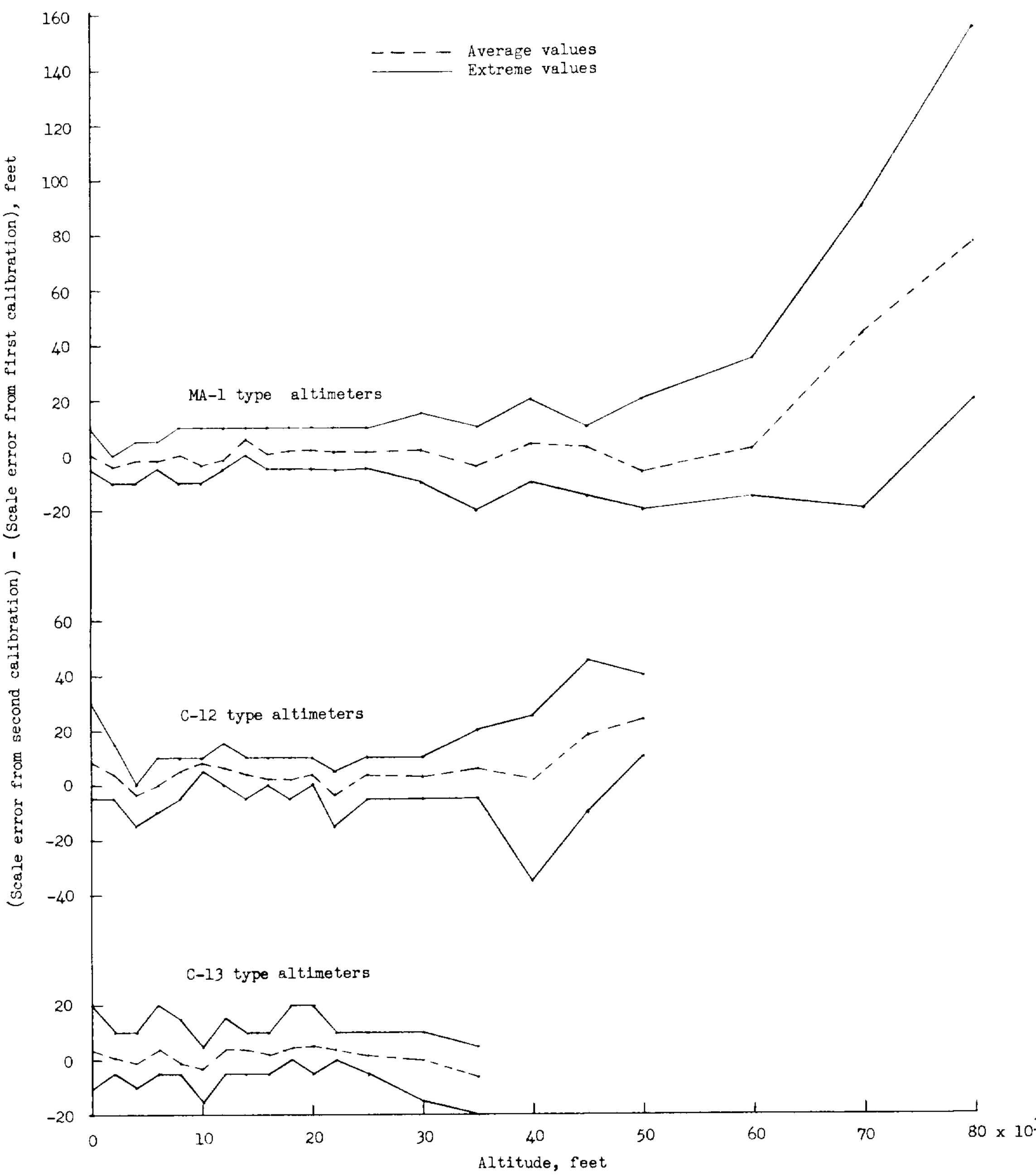

Figure 10.- Average and extreme values of the scale-error repeatability of ten C-13 altimeters, eight C-12 altimeters, and ten MA-1 altimeters.

L-1580

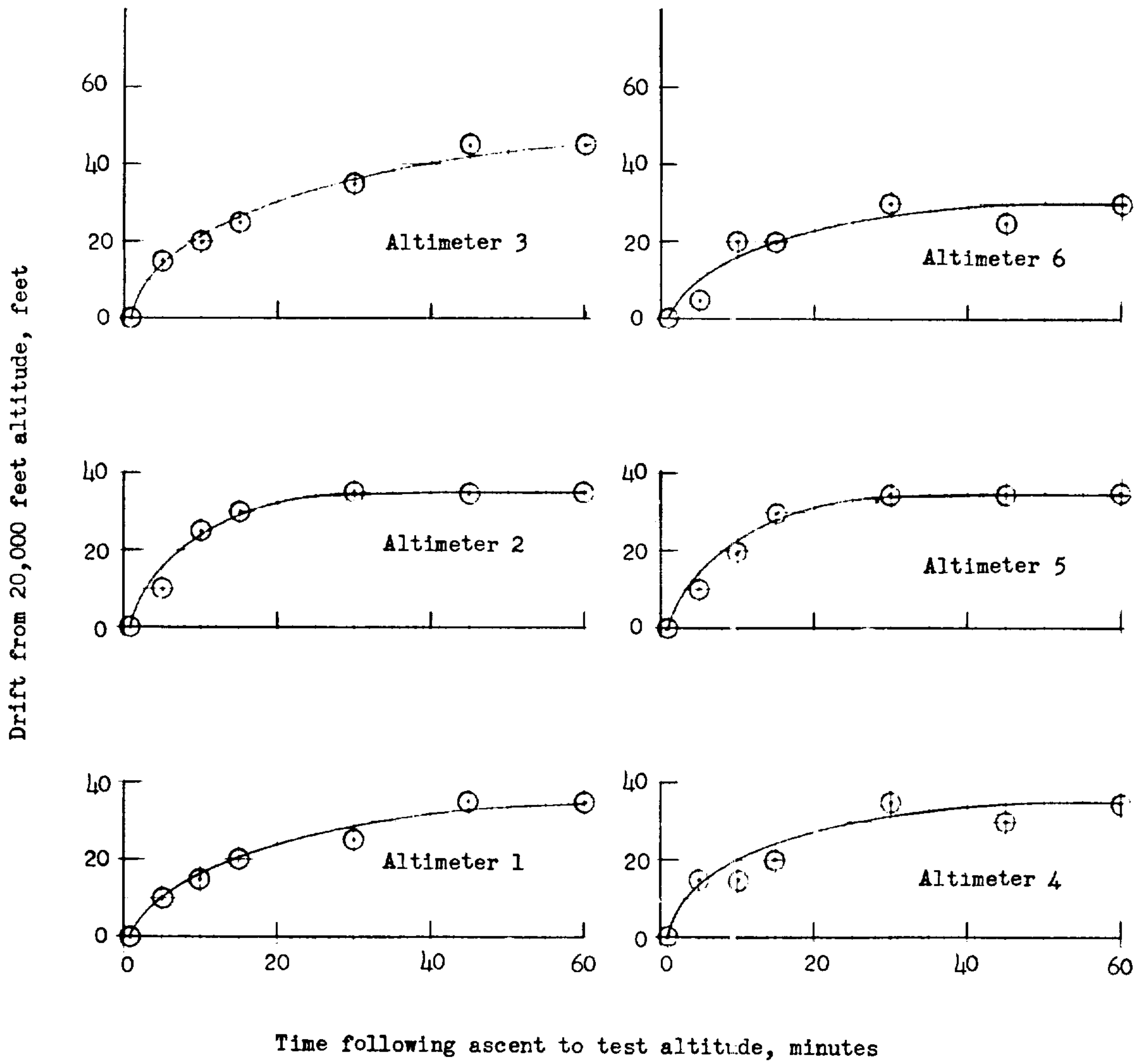

Figure 11.- Drift of six C-13 altimeters over a 1-hour period at an altitude of 20,000 feet.

L-1580

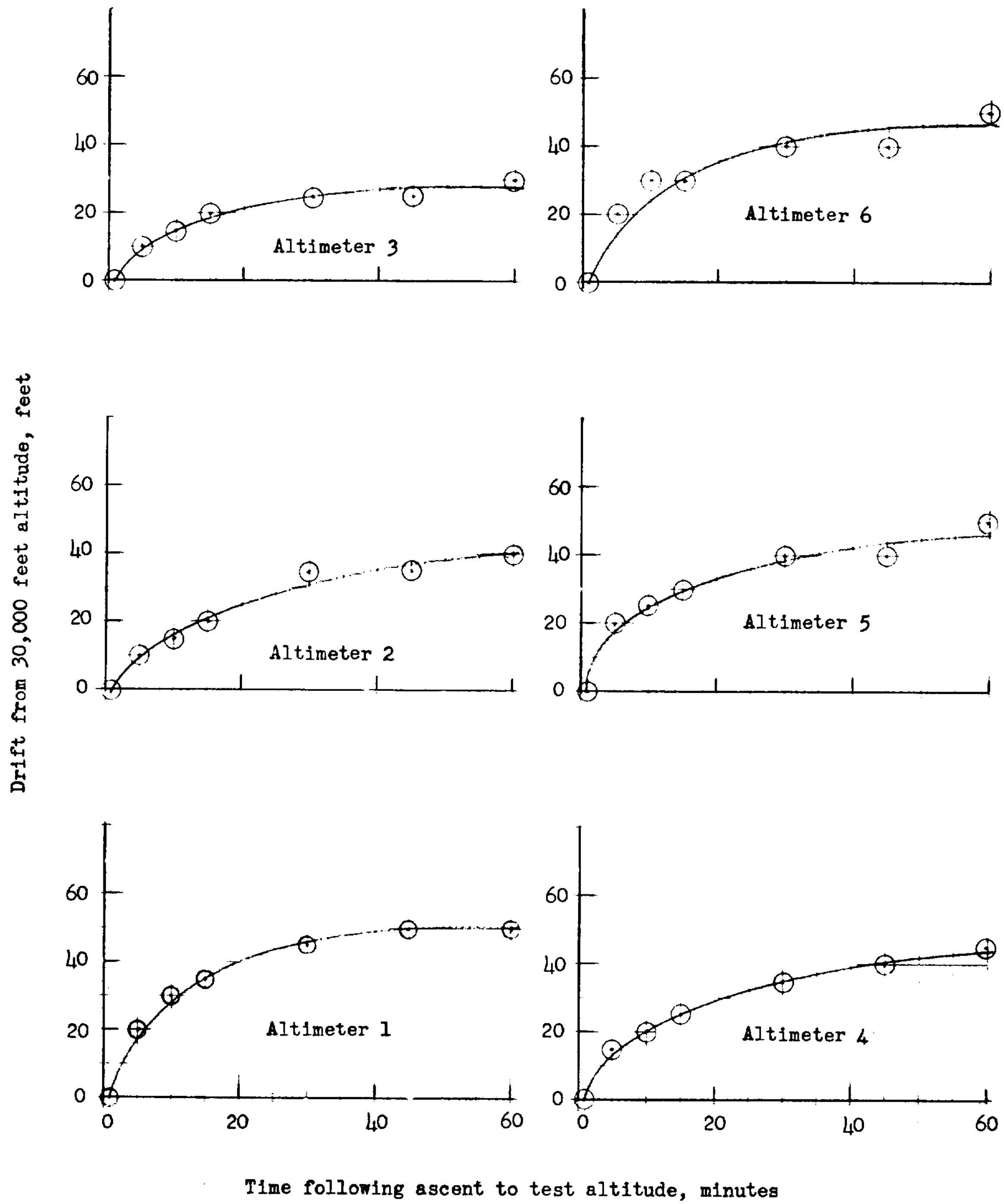

Figure 12.- Drift of six C-13 altimeters over a 1-hour period at an altitude of 30,000 feet.

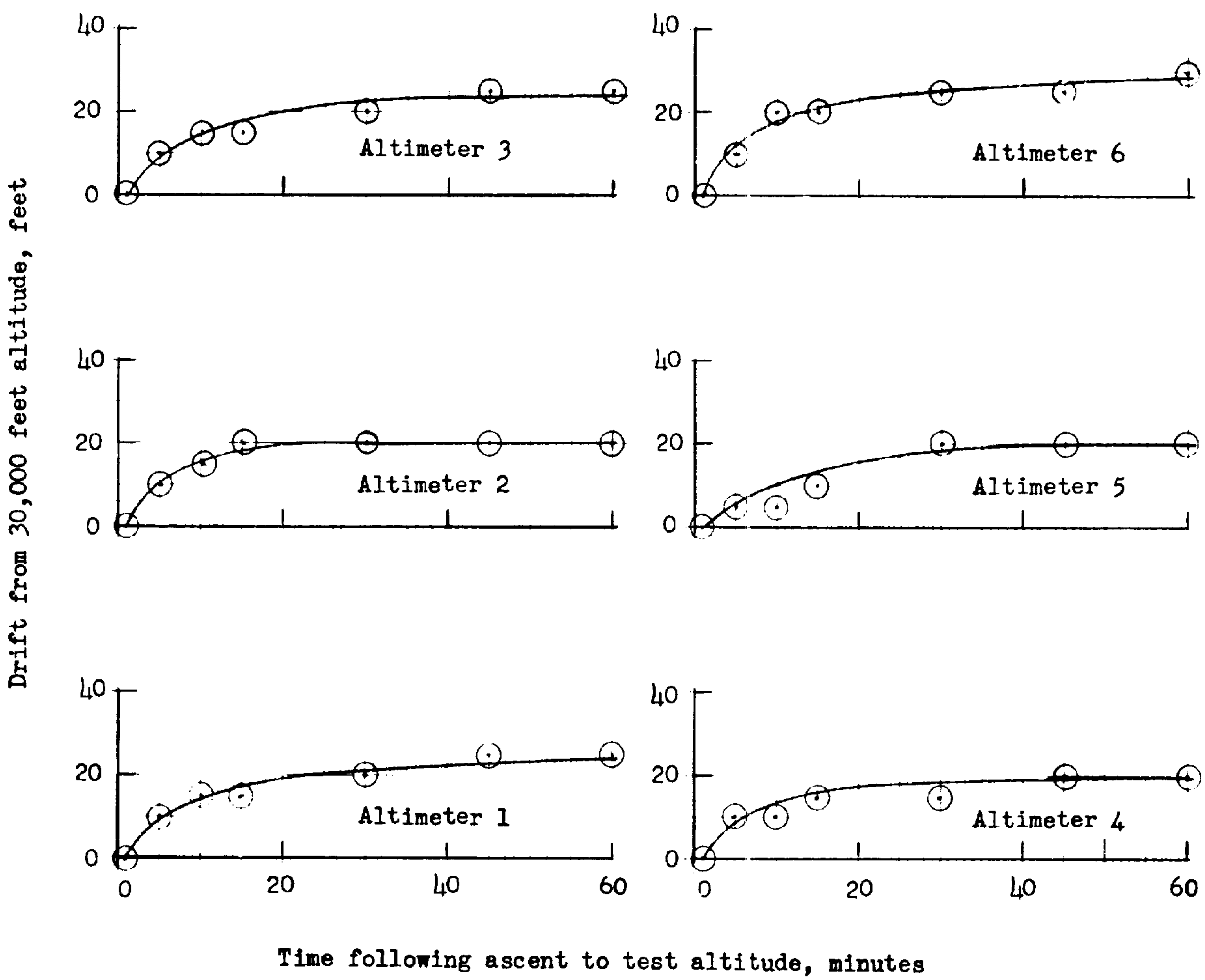

Figure 13.- Drift of six C-12 altimeters over a 1-hour period at an altitude of 30,000 feet.

L-1580

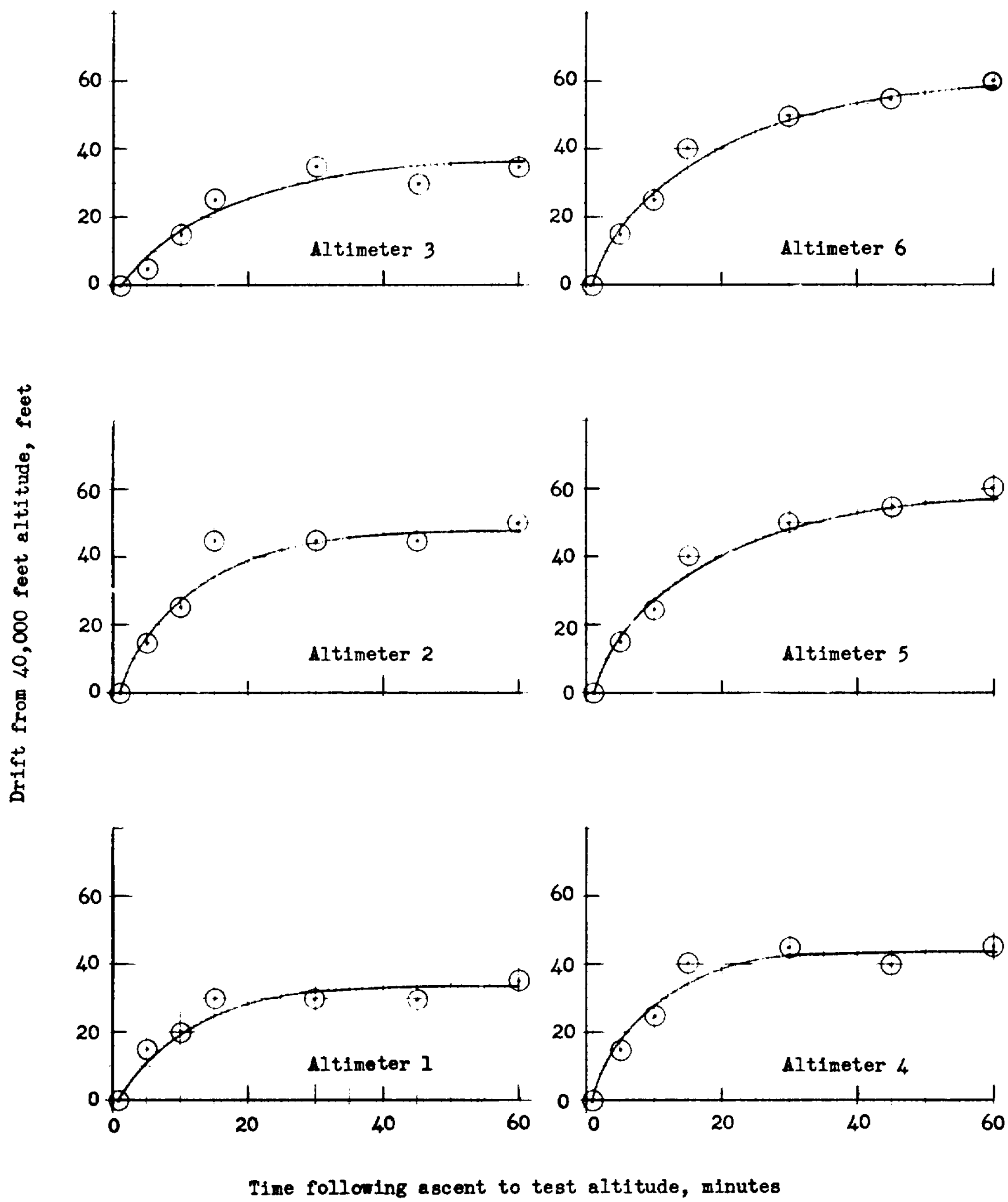

Figure 14.- Drift of six C-12 altimeters over a 1-hour period at an altitude of 40,000 feet.

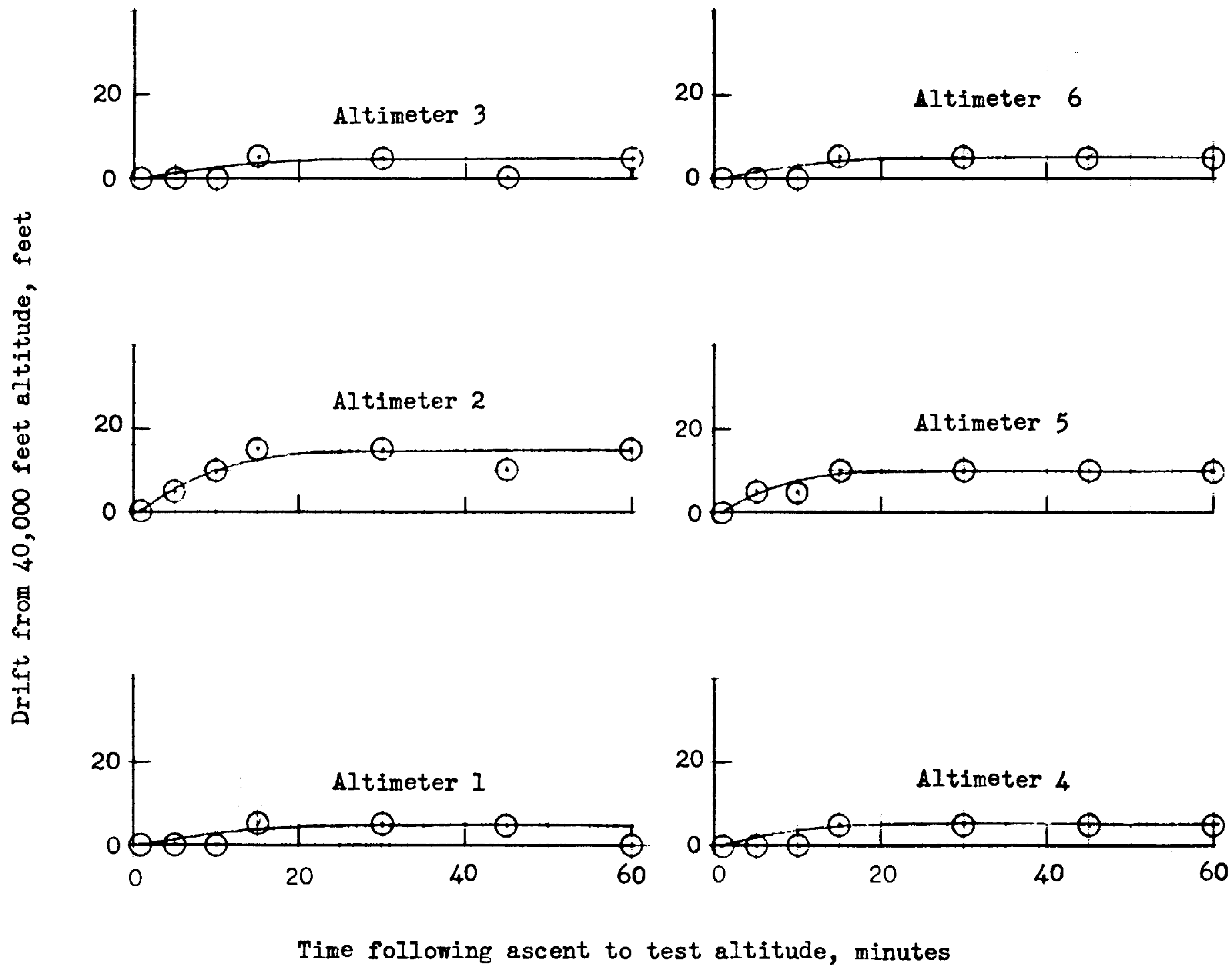

Figure 15.- Drift of six MA-1 altimeters over a 1-hour period at an altitude of 40,000 feet.

L-1580

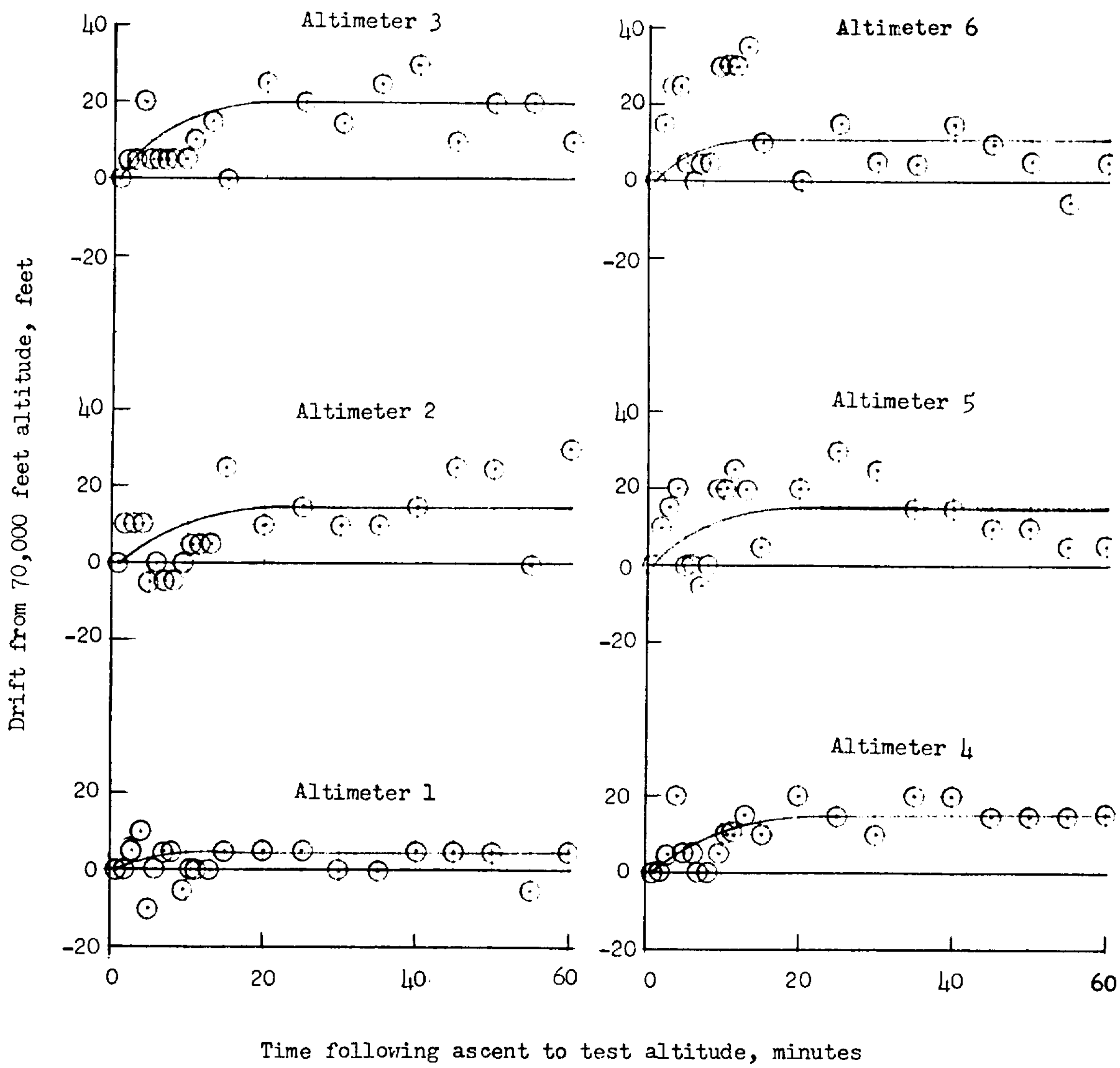

Figure 16.- Drift of six MA-1 altimeters over a 1-hour period at an altitude of 70,000 feet.

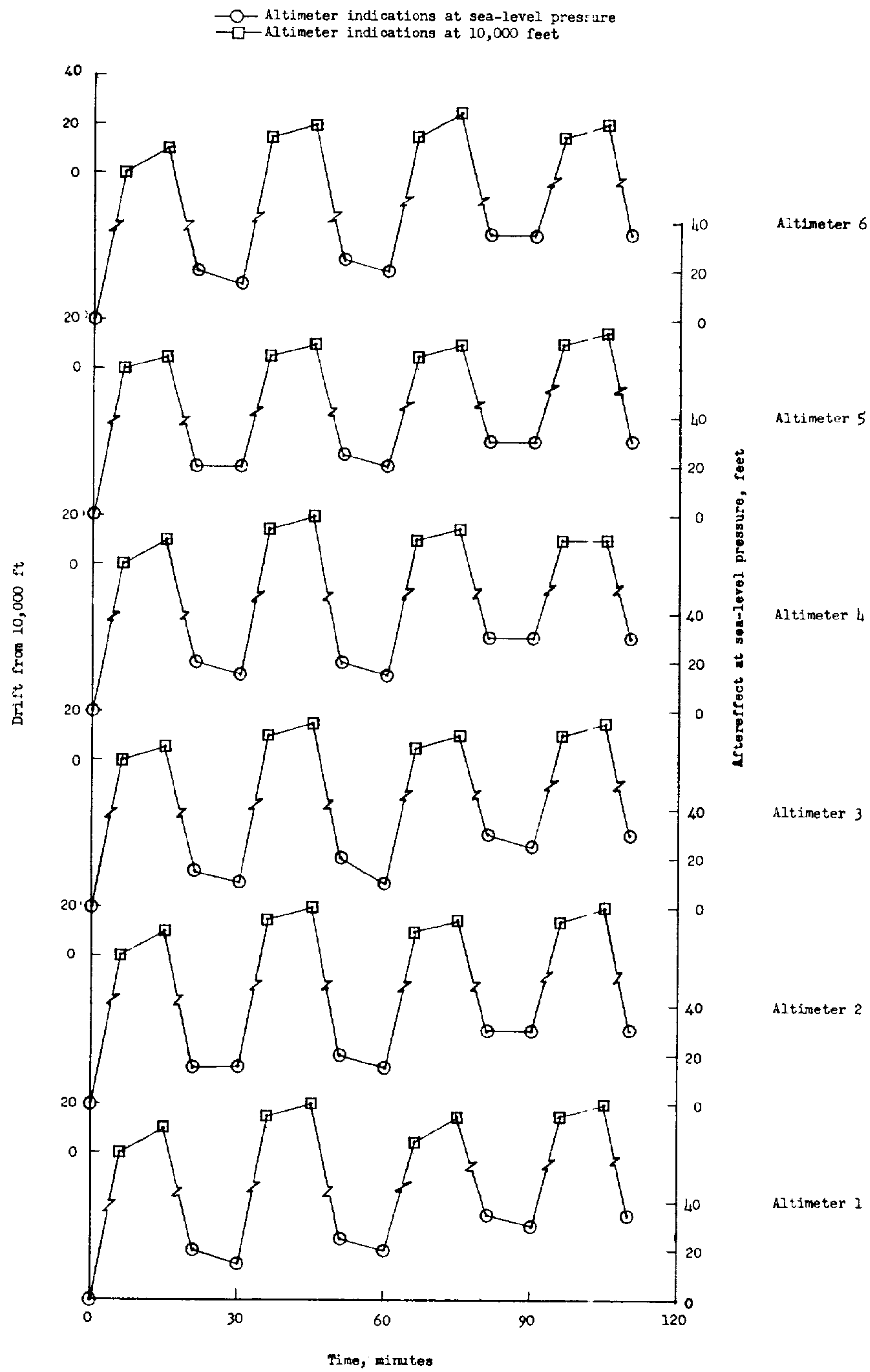

Figure 17.- Drift and aftereffect of six C-13 altimeters during four simulated 10-minute flights at 10,000 feet.

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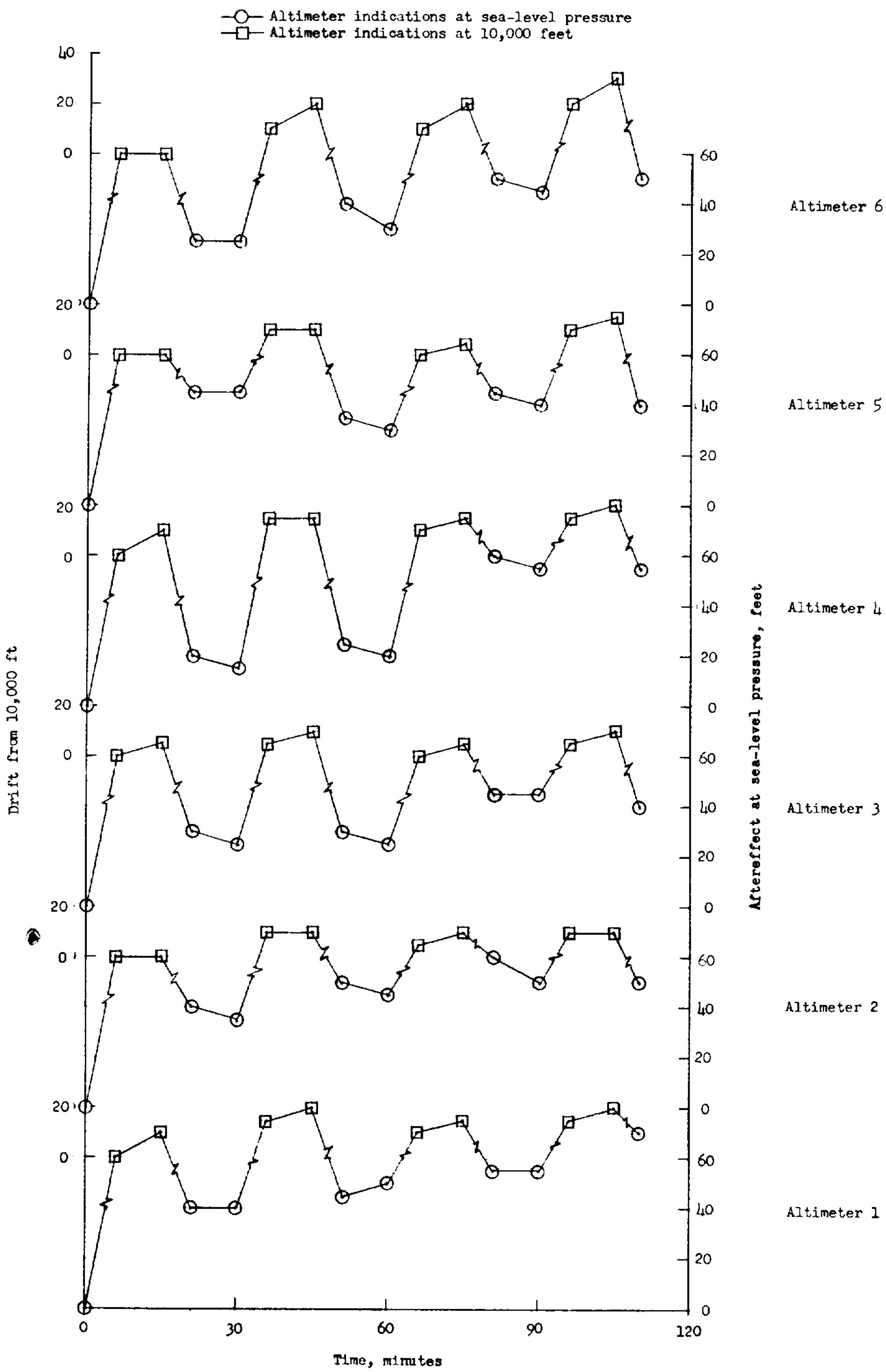

Figure 18.- Drift and aftereffect of six C-12 altimeters during four simulated 10-minute flights at 10,000 feet.

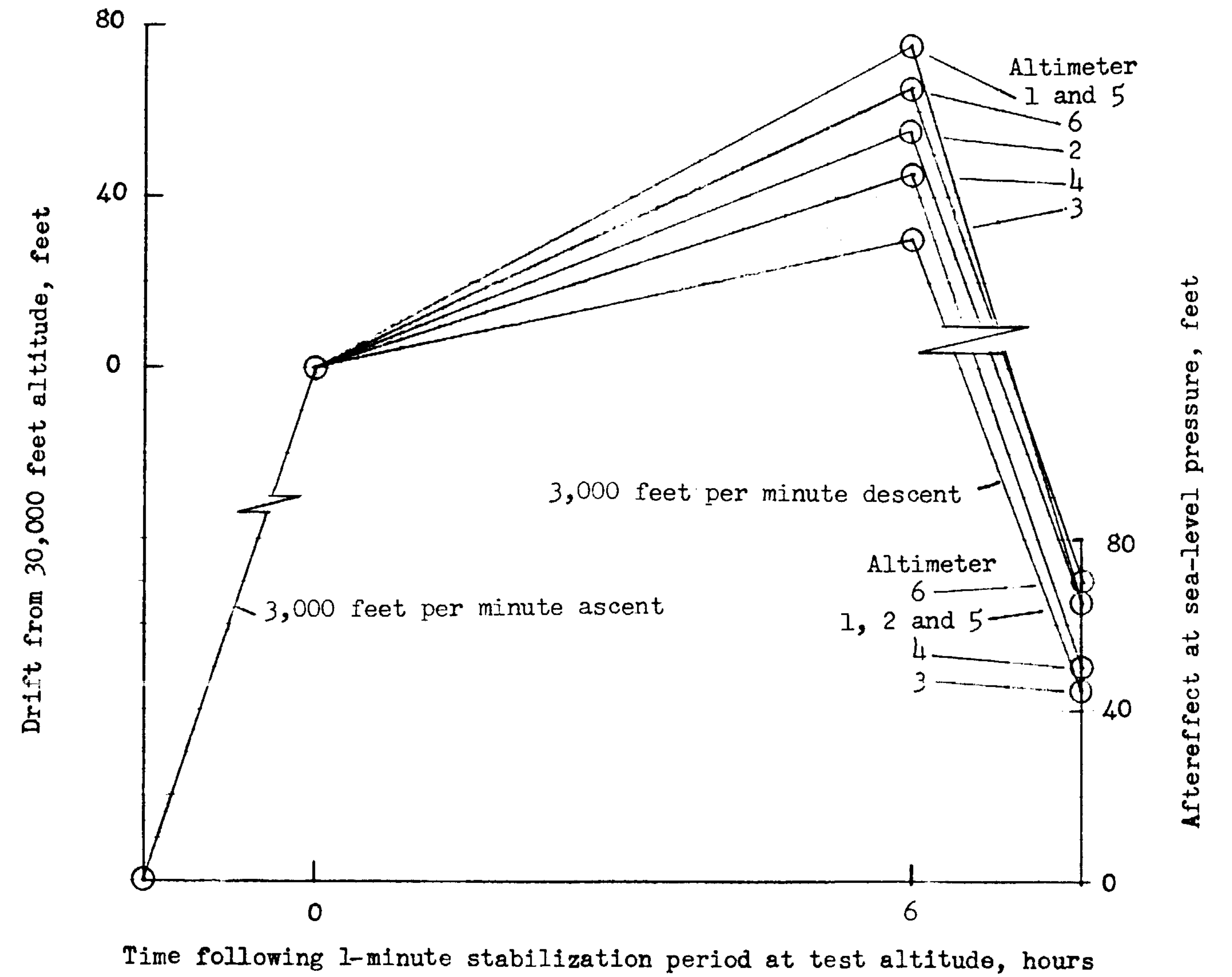

Figure 19.- Drift and aftereffect of six C-13 altimeters for a simulated 6-hour flight at 30,000 feet.

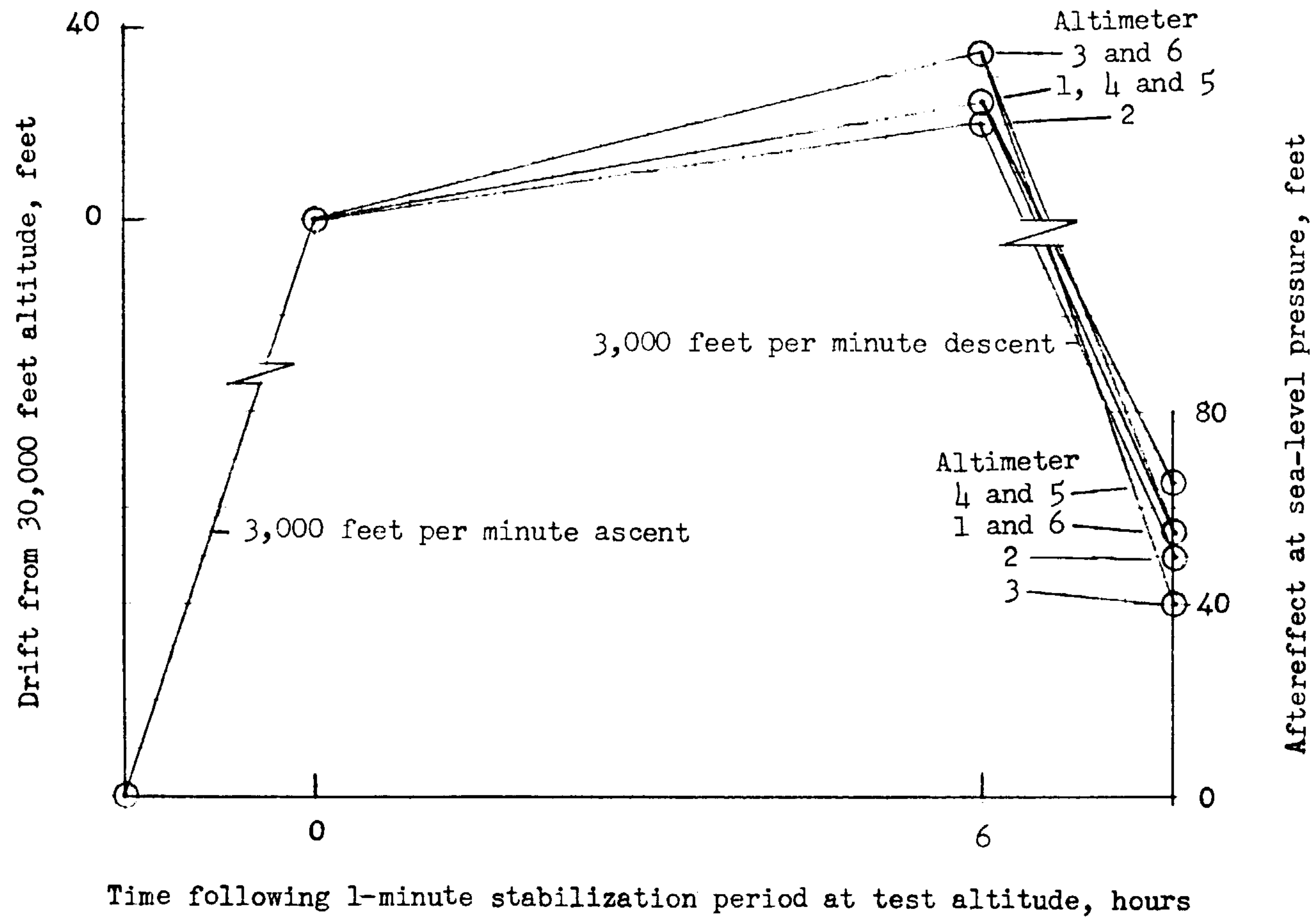

Figure 20.- Drift and aftereffect of six C-12 altimeters for a simulated 6-hour flight at 30,000 feet.

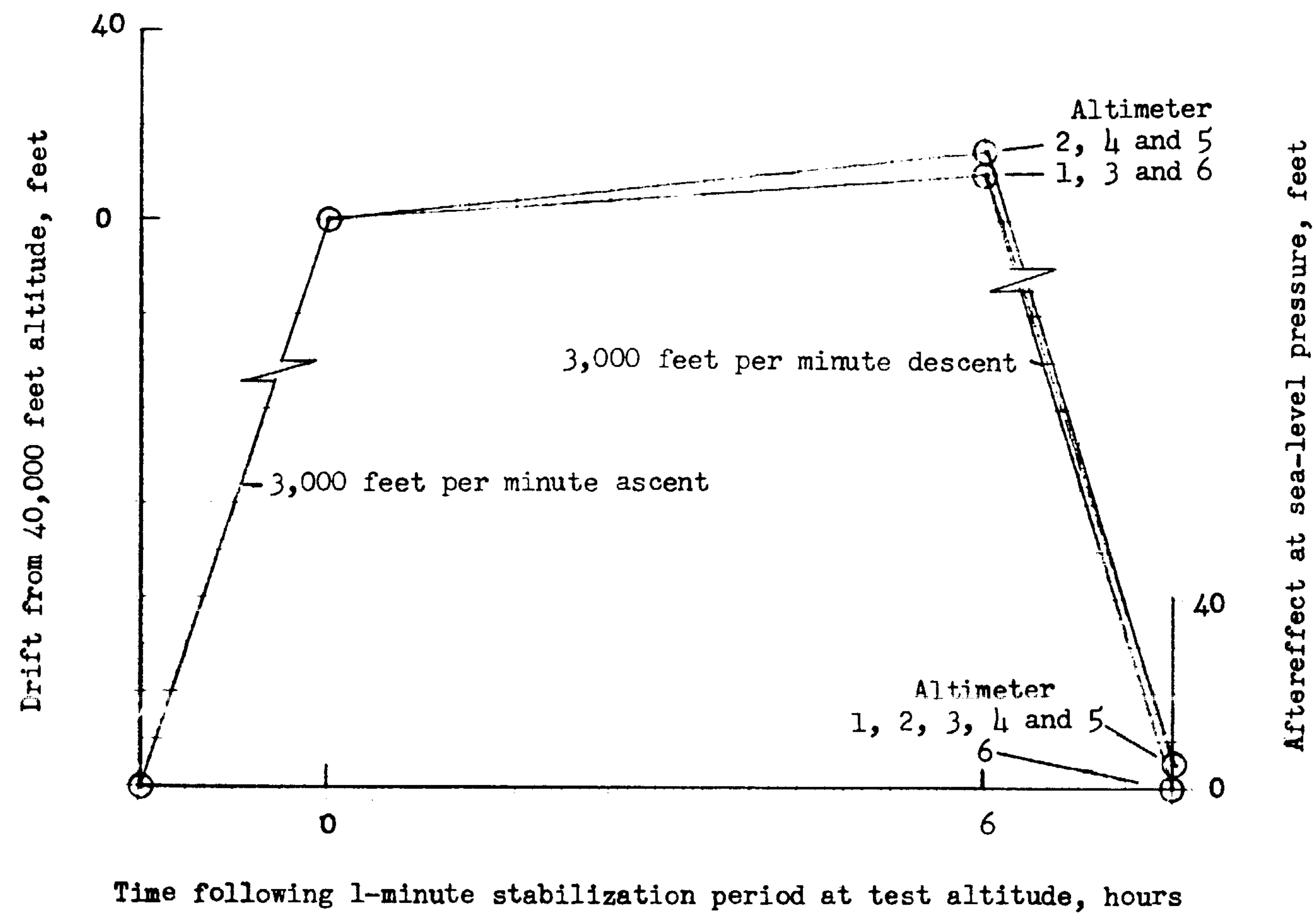

Figure 21.- Drift and aftereffect of six MA-1 altimeters for a simulated 6-hour flight at 40,000 feet.

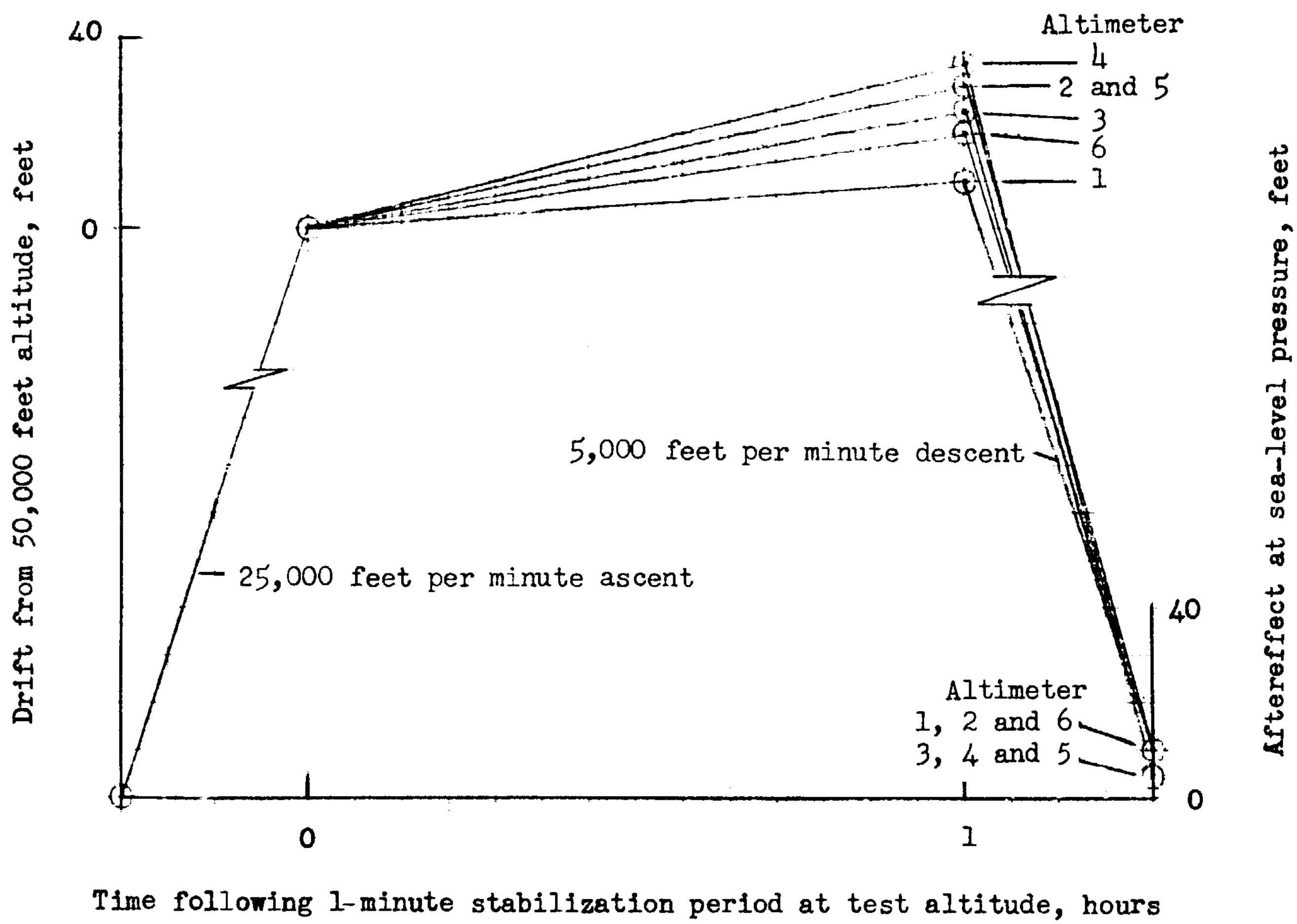

Figure 22.- Drift and aftereffect of six MA-1 altimeters for a simulated 1-hour flight at 50,000 feet.

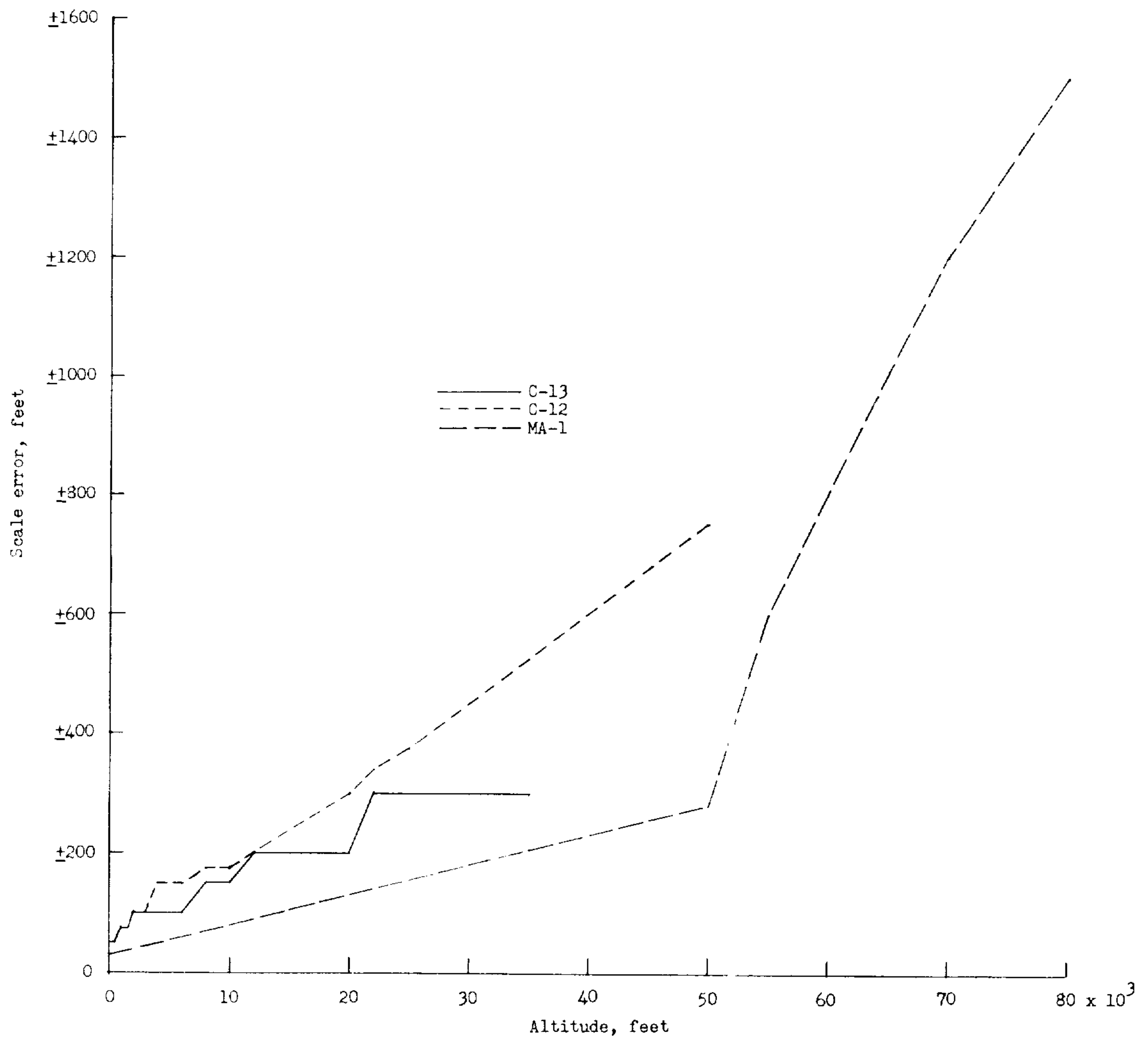

Figure 23.- Scale-error tolerances for C-13, C-12, and MA-1 altimeters (taken from refs. 1 and 3).