DEPARTMENT OF COMMERCE

CIRCULAR
OF THE
BUREAU OF STANDARDS

S. W. STRATTON, DIRECTOR

No. 46

TESTING OF BAROMETERS AND ALTIMETERS

[THIRD EDITION]

The first and second editions of this circular were issued under the title "The Testing of Barometers"

DECEMBER 26, 1922

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TESTING OF BAROMETERS AND ALTIMETERS.

ABSTRACT.

This circular describes the testing of mercurial and aneroid barometers at the Bureau of Standards and announces the fees which are charged for the various tests.

CONTENTS.

I. MERCURIAL BAROMETERS.

1. USES.

Mercurial barometers are used (1) as primary standards with which other barometers may be compared; (2) as laboratory standards of high accuracy for determining the pressure of the atmosphere or the pressure in a closed system in connection with the determination of steam points, the pressure coefficient of chemical reactions, and similar operations; (3) in a moderately portable form to indicate altitude in mountain explorations; and (4) with less attention to the greatest attainable precision for numerous meteorological and engineering purposes.

2. ERRORS OF MERCURIAL BAROMETERS.

The errors most commonly encountered in mercurial barometers are those due to capillarity, scale graduation and scale mounting, and residual gas in the evacuated tube. The capillary depression of the mercury column in a barometer tube of 1 cm internal diameter is of the order of 0.2 to 0.4 mm. It is greater the greater the meniscus height above the circle of contact between the mercury and the glass tube and less the greater the bore of the tube. The capillary depression becomes excessive in tubes of very small bore, and in any given tube it is likely to vary from day to day as well as from point to point of the tube. In spite of this fact it is generally not customary to isolate the capillary error from the scale errors, although the net effect of capillarity and scale errors may conveniently be separated from the error due to residual gas. The gas error increases as the mercury approaches the top of the tube. Consequently barometers should be adjusted to read with the mercury as far as possible below the top of the tube. Within the limits of the inconstancy of the capillary error the over-all instrumental correction of the mercurial barometer can usually be determined once for all and designated for practical use by a single numerical quantity unless the gas correction is a predominant factor, in which case the over-all correction can be expressed by an empirical calibration curve or the equation thereof. Such a correction need only be redetermined as a precaution against improper filling or the effects of rough handling.

Assuming the barometer itself to be perfect and regarding it purely as an instrument for determining pressure, corrections must be applied to reduce the reading to what it would have been if the acceleration of gravity had had a certain standard value and the mercury and the scale had been at a certain standard temperature. Complete corrections to the mercurial barometer for temperature and gravity are to be found in the Smithsonian Meteorological Tables and elsewhere. Strictly speaking, the barometer measures pressure only, any fixed relation between pressure and altitude being impossible. Practically, however, a relation can be formulated which is approximately correct by assuming for the air column a particular mean humidity, a particular mean temperature, and perfectly static conditions. Such a relation is afforded by the Bureau of Standards altitude-pressure table given in the appendix of this circular. This table is in common use for graduating the scales of aircraft altimeters manufactured in America. The

British table is practically the same as the American table. Airy's scale, which begins at 31 inches instead of 29.90 inches of mercury, is more commonly applied to aneroids which are used for other purposes.

3. METHODS OF TESTING MERCURIAL BAROMETERS.

The methods of testing mercurial barometers differ considerably according to the uses for which the barometers are intended. These differences of method depend chiefly on the standard which is to be used during the tests, on the necessary range of pressure and means of controlling the same, and on the total number of observations necessary to obtain a suitable degree of precision.

The gas correction of primary standard mercurial barometers is determined at the Bureau of Standards by forcing the mercury nearly to the top of the tube while comparing from point to point the indications of the barometer with those of an auxilliary barometer. During the comparison of mercurial barometers attention is given to the elimination of temperature gradients along the tube as well as temperature lag.

For laboratory standards, which are secondary instruments, the gas correction is not isolated from the other corrections, but an over-all calibration correction is obtained by comparison with another barometer connected to the same pressure-tight system while the pressure is varied over the desired range. In tests of the highest precision, reference is made directly to a primary standard barometer, but in the majority of tests the use of a previously standardized secondary barometer is sufficient. Frequently the use to which laboratory standards are to be put does not demand a complete calibration curve, and a simple test at atmospheric pressure is sufficient. Marine or compensated-scale barometers giving no indication of the position of the mercury in the cistern should, however, always be calibrated over a wide range of pressure.

High-altitude mercurial barometers are tested in a similar way except that even for testing at a single point it is necessary to control the pressure artificially in order that the mercury may stand at the desired height. Simple testing at one point will not serve to detect the existence of air in the evacuated space, and consequently a correction so furnished is valid only in the immediate neighborhood of the particular pressure at which it was determined.

For commercial barometers of a lower grade, such as may be used for computing the condenser pressure in steam-engine tests in conjunction with the reading of a differential gage, or for determining the range corrections in Artillery practice, or for many meteorological purposes, the tests are, in principle, carried out in the same manner as described above. They are executed more quickly, however, and in view of the small internal diameter of the tubes employed in this lower grade of barometer, observations to so high a degree of precision as before would be superfluous.

Figure 1 shows several mercurial standards and a vacuum control board of special design used in barometer testing at the Bureau of Standards. Below the barometers is a large reserve vacuum tank. The tank is of value in minimizing the effects of slight leaks that may occur in the system. This arrangement of barometers, vacuum-control board, and tank makes it possible to produce desired pressures at several points simultaneously.

4. CERTIFICATION OF MERCURIAL BAROMETERS.

Certificates for mercurial barometers are not issued by the Bureau of Standards. Instead the instrumental corrections to be applied are given. These can ordinarily be designated by a single number applicable throughout the scale range.

II. ANEROID BAROMETERS.

1. USES.

Aneroid barometers are inherently less accurate than mercurial barometers, but are widely used for a variety of purposes where mercurial barometers would be inconvenient or impractical. For example, they are used for meteorological observations, as on board ship, or for the determination of absolute altitudes, either with a slow rate of change of pressure as in mountain climbing, or with a rapid change of pressure as in aviation; also in a great many engineering enterprises to determine relative differences in altitudes, as in estimating the available water power of streams and of waterfalls. Finally, they may be used for interpolation between known altitudes not very far apart, as in establishing contour lines, which is an entirely practicable use of the aneroid barometer, provided proper precautions are taken.

2. ERRORS OF ANEROID BAROMETERS.

The errors of an aneroid barometer depend to a considerable extent upon the conditions under which the instrument is being used and may, indeed, undergo secular changes. It is, however,

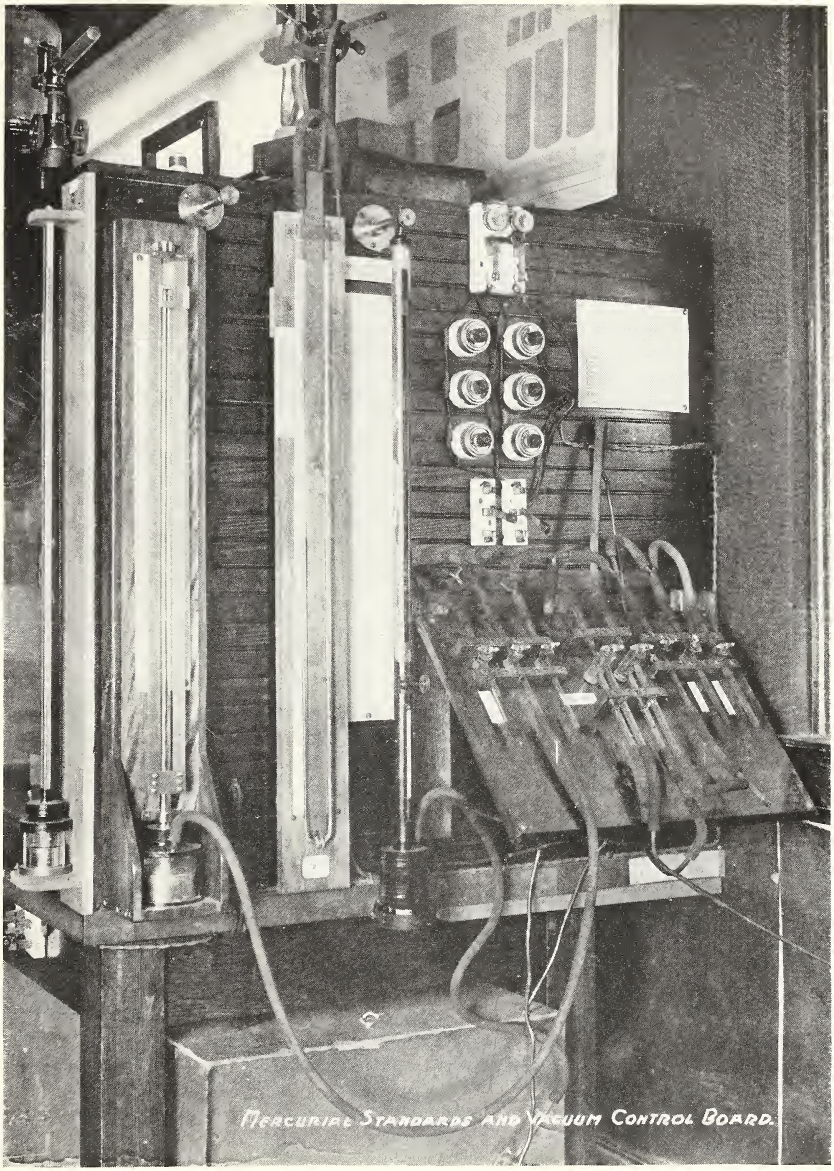

FIG. 1.—*Mercurial standards and vacuum control board.*

by no means true that the aneroid barometer is entirely erratic and undependable, for while the errors of these instruments are numerous, large, and variable, their magnitude can be approximately determined in each case. The variation of any given error, though perplexing to a person obliged to use the instrument, appears to follow definite physical laws. While, then, it is true that corrections for the errors of an aneroid barometer can not be so satisfactorily made as can those of a mercurial barometer they can nevertheless be determined to a practical degree of accuracy depending on the time and care which is devoted to testing and correcting the instrument, providing, of course, that the aneroid is initially free from mechanical defects.

The errors of aneroid barometers may be classified as transient, secular, and inherent. Transient errors are those due to the aneroid not being in a physically steady state. They can be avoided by waiting long enough before reading. Secular errors are those due to changes taking place over a long period of time. While true secular errors may exist owing to the gradual settling of the parts, as was found in certain instruments constructed hurriedly during the recent war, these need not be of serious concern if the instrument is checked up from time to time with a standard mercurial barometer. Besides the true secular changes there are rather sudden changes which would on first thought be supposed to be secular changes but which are either shown by close observation to be sufficiently explicable in terms of elastic lag resulting from the daily fluctuations of atmospheric pressure, or which may be ascribed to some actual injury of the instrument. The inherent errors are those due to imperfections of design or construction and to the physical properties of the materials used in construction. These may be subdivided under three heads, namely, mechanical errors, thermal errors, and elastic errors.

The chief mechanical errors are those due to the necessity for a compromise between friction and backlash in the linkwork and those due to the difficulty of securing perfect balance among the movable parts. To minimize the effect of mechanical errors, (1) always read the aneroid in the position in which it was tested, and (2) tap the instrument sharply just before reading.

Thermal errors are due to the expansion of the parts and to change of the stiffness of the elastic members of the aneroid (the spring and aneroid capsule) with varying temperature. To correct for these errors, the instrument should be tested under as great a range of temperature as will be encountered in practice.

Aneroids which are marked "compensated" are only compensated for the effect of changes of temperature on the readings at sea-level pressures and do not take into consideration the effect of change of stiffness of the elastic system on the readings at low pressures. Some aneroids which are well compensated at sea level for ordinary temperatures show very inadequate compensation at extreme temperatures. Instruments can be purchased, however, which are successfully compensated over a range of 100° F.

Elastic errors are caused by the imperfect elasticity of the metal of the aneroid capsules and springs. These errors are usually designated by the single term "elastic lag" and may be classified under the three following designations: (1) Drift, which is the increase of reading when the instrument is held at a constant low pressure for several hours; (2) hysteresis, which is the excess of the reading with increasing pressure over that with decreasing pressure for a given pressure and which is also evidenced by the fact that the reading at any given pressure depends on the previous rate of change of pressure; and (3) after-effect, which is the amount by which the pointer fails to come back to the initial reading after any complete cycle of pressure changes; for example, the failure of the pointer to return to its initial reading when the instrument is brought back to the original ground pressure.

The existence of the first of these effects necessarily leads to that of the other two. Whether there exists a type of hysteresis due to reversal of action independently of time or not (recent experiments on springs at the Bureau of Standards seem to point to this type of hysteresis), it is probable that the predominating errors are those due to drift. The most important precaution to take in order to avoid the effect of elastic errors is to ascertain in advance, and most conveniently by the regular bureau test, the drift which takes place in, say, five hours. In fact, it is possible to correct, roughly, for the effect of elastic errors when the exact circumstances under which the instrument was employed are known, particularly the rate of change of pressure.

An extensive investigation of aneroids has recently been carried out by the Bureau of Standards, the results of which have made it possible to construct aneroid barometers in which all the common errors of ordinary instruments have been practically eliminated. These instruments were made especially for use in aircraft, but the same principles of design can be applied with equal success in the construction of precision engineering aneroids. Some of the defects encountered in ordinary instruments are as follows:

(*a*) Irregular graduation of the scales.

(*b*) Altitude scales which can be rotated relative to the pressure scale when the altitude scale is not divided into equal parts.

(*c*) The barometer fitted with a mechanism properly belonging to a smaller size case.

(*d*) The substitution of flexible fiber in the multiplying system for the usual metallic strip or chain.

(*e*) The adjusting screw in the base having so large a pitch that in attempting to adjust the position of the pointer the smallest possible movement of the screw driver moves the pointer over a large part of scale. Attention should be called here to the use of this adjustment, since if the pointer has moved more than a tenth of an inch it should be reset on the arbor and the finer adjustment made with the adjusting screw.

(*f*) Instruments engraved with the word "compensated" and yet not provided with any temperature-compensation device.

(*g*) Instruments having large errors of parallax due to the pointer being set a relatively large distance from the dial. This is true of instruments employing a spiral groove on the pointer arbor as a multiplying medium.

(*h*) Excessive vibrations of the pointer in aircraft instruments.

(*i*) Changes in the character of calibration curve in certain instruments constructed during the war, when the elastic elements of the instrument were not given a chance to age properly.

3. METHODS OF TESTING ANEROID BAROMETERS.

The technique of testing all types of aneroid barometers is practically the same, but the methods of reporting the results and the rejection limits are different according to the use to which the instrument is to be put. Four kinds of tests are available, depending on the use and kind of information desired. These, in order of their importance, are (1) the general test, (2) supplementary test for sample instruments, (3) supplementary test for experimental instruments, and (4) short test for service instruments.

The *general test*, which is applied to all aviation, engineering, weather, and surveying instruments, is primarily a quality test rather than a correction test. It consists of tests for mechanical, thermal, and elastic errors, explained in detail below, and affords data for deducing approximate values of the corrections under

12172°—22——2

various working conditions. This is the test which is always given if no other is explicitly requested. It also forms a part of the test on sample instruments, and of that on experimental instruments, but is not included in the short test.

The *supplementary test for sample instruments* was developed especially for aeronautical instruments. It includes a determination of the effects of vibration, acceleration, or other conditions encountered on aircraft which are not covered by the general tests. Such observations are important in considering the suitability of new types or makes of instruments, but are not likely to be necessary in testing each individual instrument.

The *supplementary test for experimental instruments* is concerned, primarily, with the determination of the corrections to be applied to recording instruments or indicating instruments of high precision, where quick and large changes of pressure are likely to occur, as in experiments on aircraft; also to instruments that are to be used as secondary standards for testing and adjusting other aneroids. The test includes a more precise and complete determination of the errors covered by the general test and also a working test if the working conditions are known. By a working test is meant one in which the actual variations of pressure and temperature encountered in the use of the instrument on a particular occasion are artificially reproduced in the laboratory. In the case of aviation instruments this is referred to as a flight-history test, and the Bureau of Standards has been called upon from time to time to make these tests in the case of record altitude flights, since the instrument can not be expected to repeat its indications unless subjected to identical conditions. This procedure gives the most probable result in the case of an absolute altitude determination.

The *short test for service instruments* is an abridged form of the general test, recommended only when time is not available for the numerous stages of that test. The operations involved in the general test require a minimum of eight working days, but the short test can be finished in two days. In the great majority of cases the short test will suffice for the rejection of all inaccurate instruments, but occasionally one will slip through with a large drift or a larger temperature effect at high altitudes. Such effects are considered in the general test but not in the short test.

(*a*) GENERAL TEST.

The general test consists of four parts, designated as A, B, C, and D, and subdivided, as shown in Table 1, which includes also the classes of errors with which the various tests are concerned.

TABLE 1.—Errors and Defects Observed in the General Test.

Designation of test.		Errors.	Designation of test.		Errors.
A	1. Tapping	Mechanical.	B	1. Sea-level correction, cold.	Thermal.
	2. Shift	Do.		2. Sea-level correction, hot.	Do.
	3. Inclination	Do.	C	1. Calibration	Mechanical.
	4. End correction	Do.		2. Drift	Elastic
	5. After-effect	Elastic.	D	1. Partial calibration, cold	Thermal.
	6. Defects			2. Partial calibration, hot	Do.

TEST A (PRELIMINARY TEST).—This consists of six parts—tapping, shift, and inclination tests, the determination of the correction at the end of the range and of the after-effect by means of a pressure test, and a final examination for mechanical defects. Of course, any obvious mechanical defects that are noted upon receipt of the instrument may cause its rejection without carrying out any of the experimental tests.

(1) The *tapping test* is made by repeatedly tapping the instrument vigorously enough just to disturb the pointer and noting the average deviation of the pointer reading from its mean position. Four or five taps are usually sufficient.

(2) For the *shift test* the aneroid is held in the operator's left hand, with the dial in a vertical plane facing the operator and the pointer horizontal. It is then struck on the edge with the right hand vigorously enough to disturb the pointer, after which the instrument is turned so that the dial is horizontal and read. The process is then repeated, with the instrument held in the right hand and struck with the left with the dial again vertical but facing in the opposite direction. One-half the average difference between the two readings is recorded and is known as deviation by shifting or simply shift.

(3) For the *inclination test* the aneroid is held with the dial horizontal and read after being tapped lightly. It is then turned so that the dial and pointer are vertical and tapped and read again. The difference between the two readings is recorded and known as the vertical correction or inclination effect.

(4) The aneroid, having been set to read pressure or the altitude as indicated by the pressure of the mercurial standard,[1] is placed in a container and the pressure reduced at once to the lowest point on the scale (the lowest pressure or the highest altitude). The movement of the pointer is carefully watched during this pressure change to detect jerkiness. After the pressure has been reduced the aneroid is allowed to stand for a period equal to two-thirds of

[1] The altitude may be computed from data in the Appendix.

the time required to ascend to that pressure at a rate of 0.2 inch per minute. At the end of this rest period the readings of the standard and of the aneroid are recorded. The pressure in the container is now quickly raised to full atmospheric pressure by opening the vacuum system to the air.

(5) Five minutes afterwards the aneroid and the standard are again read. The amount by which the pointer fails to come back to the true pressure or altitude is called the after-effect. This is to be expressed in percentage of the range.

(6) Mechanical defects, such as jerkiness, parallax, or loose parts, which have been noted during the foregoing test or which may now be found by further inspection are recorded. The design of most aviation aneroid barometers is now such that the tapping, shift, and inclination tests are unimportant, but these tests are essential in surveying aneroids. An error of 50 feet for altimeters or 0.05 inch of mercury for aneroid barometers is excessive. If the aneroid passes satisfactorily the six steps of test A, it is put through test B; otherwise it is rejected at this point.

TEST B (SEA-LEVEL TEMPERATURE TEST).—This test consists of two steps: (1) After the instrument has been at a room temperature of 20° C. for at least three hours it is tapped and the pointer set to the pressure or altitude indicated by the mercurial standard; this reading is recorded. It is then placed in a temperature chamber, where the temperature is lowered to −10° C. and held at this temperature for at least three hours. At the end of this period the instrument is again tapped, and the position of the index is recorded and compared with the reading of the standard.

(2) The aneroid is next put through the hot test, which is the same as the cold test except that the instrument is heated to +40° C. and a reading taken after a four-hour interval. From the high temperature the instrument is allowed to cool to room temperature. After three hours it is read again and compared with the standard. This completes the temperature test at atmospheric pressure.

The individual steps of test B are performed in the order given to avoid the condensation of vapor within the instrument, which would occur if it were first heated and then cooled, but which is avoided by heating the instrument after the cold test. Care should always be taken to tap the instrument before reading.

TEST C (CALIBRATION AND DRIFT).—(1) After setting the index to the pressure or altitude indicated by the standard the instrument is placed in a container and the pressure decreased at an average rate of 200 feet per minute for aviation instruments and 0.2 inch of mercury per minute for other aneroids. Simultaneous readings of the instrument under test and the mercurial standard are taken at intervals of five minutes. The difference between the two readings is the correction, which is so given that the algebraic sum of the correction and the reading of the instrument under test equals the true pressure or altitude.

(2) After the pressure in the container has been reduced at the above specified rate to correspond to the lowest pressure or highest altitude indicated on the scale it is held at this pressure for five hours. At the end of this period the container is tapped and the instrument read and the correction obtained as before from the mercurial standard. Extreme care must be taken that the temperature of the instrument does not change during the test, and that the pressure in the container is exactly the same at the beginning and the end of the five-hour period. To avoid errors due to elastic lag, the pressure must not be allowed to fluctuate more than 5 per cent of the total pressure change during the five-hour period.

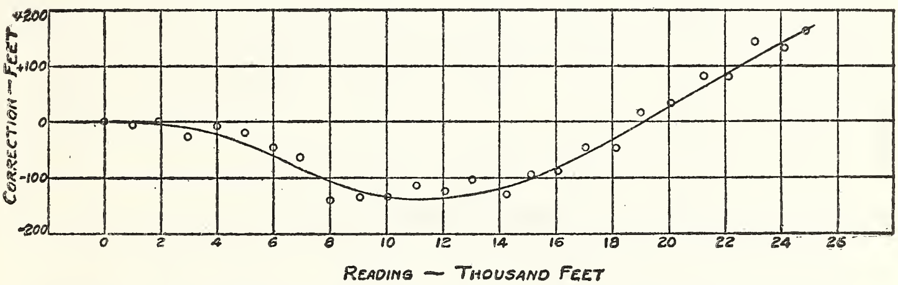

FIG. 2.—*Calibration curve of 25,000-foot altimeter at a temperature of 22° C.*

The maximum correction of the aneroid barometer reading is noted and usually a calibration curve is drawn, corrections against readings, and attached to the report. Figures 2 and 3 are typical calibration curves—Figure 2 for an altimeter and Figure 3 for an aneroid barometer. The percentage drift is found by dividing the increase in reading when the instrument is held for five hours at a given deflection by the pressure difference or corresponding altitude change to which the instrument was subjected to produce this deflection and multiplying the quotient by 100. The average deviation may be defined as the average of the deviations of the calibration curve from a straight line so drawn through the calibration curve that the sum of the squares of the deviations of the corrections is a minimum.

TEST D (ALTITUDE-TEMPERATURE TEST).—This consists of two additional calibration tests: (1) At a temperature of −10° C., (2) at a temperature of +40° C.

The corrections are found in the same manner as in test C (1). Straight lines are drawn through the calibration curve at each temperature, including the calibration at +20° C. This will give three straight lines. The slope of the calibration curve at +20° C. should always lie between the other two, the slope of the calibration curve at −10° C. being greater and that at +40° C. being less, if they are for curves whose coordinates are in altitude units.

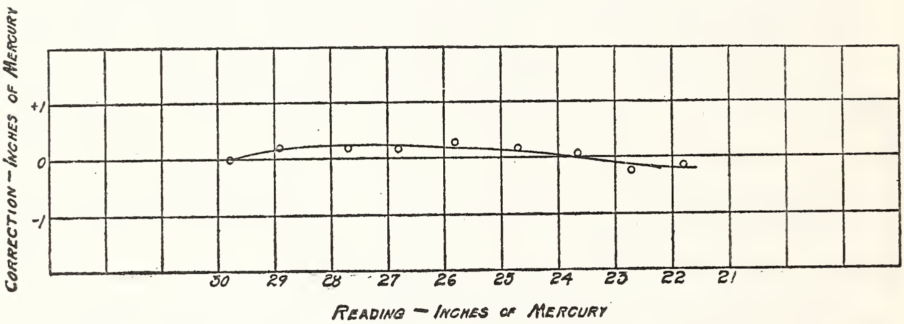

FIG. 3.—*Calibration curve of surveying aneroid at a temperature of 30° C.*

The percentage change of scale value [2] is found from the straight lines obtained from the above temperature tests at −10 and +40° C. The intermediate slope at +20° C. is of value in showing the regularity of the change of scale value with temperature, and it is also useful as a check on the other data. The percentage slope of each of the straight lines mentioned above is computed by dividing the difference in the corrections for any two pressures or altitudes by the corresponding pressure or altitude interval, taking account of signs and multiplying by 100. This value added algebraically to 100 will give the scale value in per cent. The difference in the scale values at −10 and +40° C. gives the per cent change of scale value.

The four tests are purposely given in the order named. Defects due to poor workmanship can usually be discovered before the

[2] The scale value of an aneroid barometer or altimeter is defined as the ratio of the pressure or altitude change indicated by the standard to the change indicated by the instrument and is generally expressed in per cent. That is, an instrument in perfect calibration has a scale value of 100 per cent and an instrument indicating too large a pressure or altitude change less than 100 per cent.

instrument is calibrated, and if the defect is serious the instrument is immediately rejected, thus saving time and labor. Again, the temperature test B is given before the calibration, because more instruments fail on this one test than on any other. Moreover, the instruments are thus given a chance to rest after being strained by undergoing test A. This is an important factor which should not be overlooked. The instruments must be allowed at least 24 hours' rest after being subjected to a large pressure change in order to obtain accurate results. This is because, owing to elastic errors, the instrument will give readings which differ from those obtained after a sufficient period of rest.

(*b*) SUPPLEMENTARY TEST FOR SAMPLE INSTRUMENTS.

Sample instruments are given a vibration test for one week. The instruments during this test are mounted on the vibration apparatus described below. During the test frequent observations are taken both on the oscillations of the pointer and on any movements of the dial which may take place. Immediately after and also one month after the test the instruments are calibrated again. Observations are also made on any other suspected sources of error.

(*c*) SPECIAL TESTS ON EXPERIMENTAL INSTRUMENTS.

Instruments to be used in experiments on aircraft are carefully readjusted to give the least possible errors, and calibration curves are then determined. The flight-history test referred to above is also given for such instruments when the actual flight conditions are known. Only by such a test can the effects of elastic fatigue and temperature lag be properly determined.

HIGH-ALTITUDE BAROGRAPHS.—In addition to the general test additional tests are made on barographs that are to be used to determine the altitude of high altitude flights in order to ascertain the fitness of the instrument for this special purpose.

(*a*) The instruments are given calibration tests at the temperatures of -25 and $-40°$ C. From these calibrations and those of test D the change in scale value can be found for the low temperatures encountered in flight. The reliability of the ink and the behavior of the clock mechanisms are noted when subjected to these low temperatures.

(*b*) Since the rate of pressure change affects the indications of all aneroid barometers, two further calibrations are made at $+20°$ C., one in which the pressure is decreased 1 inch of mercury every two minutes and one in which it is changed 1 inch every minute. A check calibration in which the pressure is changed at the usual rate of 1 inch every five minutes is also made. The instruments are held at the lowest pressure for one-half hour. The pressure is then increased at the same rate at which it was decreased until atmospheric pressure is reached. The readings of the instruments and the standard mercurial barometer are taken at regular and frequent intervals.

To determine the effect of altering the rate of pressure change, calibration curves are drawn for decreasing pressures for the one, two, and five minute rates. These curves would coincide for a perfect instrument. No tolerance has been set, owing to paucity of data, but it is suggested that the coincidence of the curves should be sensibly within 0.1 of an inch of mercury for the entire range.

(d) SHORT TEST FOR SERVICE INSTRUMENTS.

This test differs from the general test given (which is recommended whenever a time interval of about eight days can be allowed for the actual execution of the tests) in the following respects: (1) Tests A and D are omitted altogether; (2) test B is made only with cooling instead of with both cooling and heating; and (3) the drift observation in test C is omitted and replaced by an observation of the after-effect. The instrument in this test is held at the low pressure for two hours only instead of for five hours.

It is inherently impossible to make the tests A, B, C, and D in less than about seven or eight days, since it is necessary that each instrument should be allowed a period of time (preferably two days) after each stage of the tests to recover from the elastic fatigue set up in the metal by virtue of the test itself. The result of cutting down the time allowance would merely be to produce deceptive figures, which will not reproduce under working conditions.

4. TESTING EQUIPMENT.

The apparatus employed for the pressure and temperature tests is essentially the same for all kinds of tests on aneroids and is shown in the following illustrations:

Figure 4 shows a temperature chamber. By the use of an ammonia system and heaters any temperature down to −35° C. may be maintained. The instruments are placed in this chamber

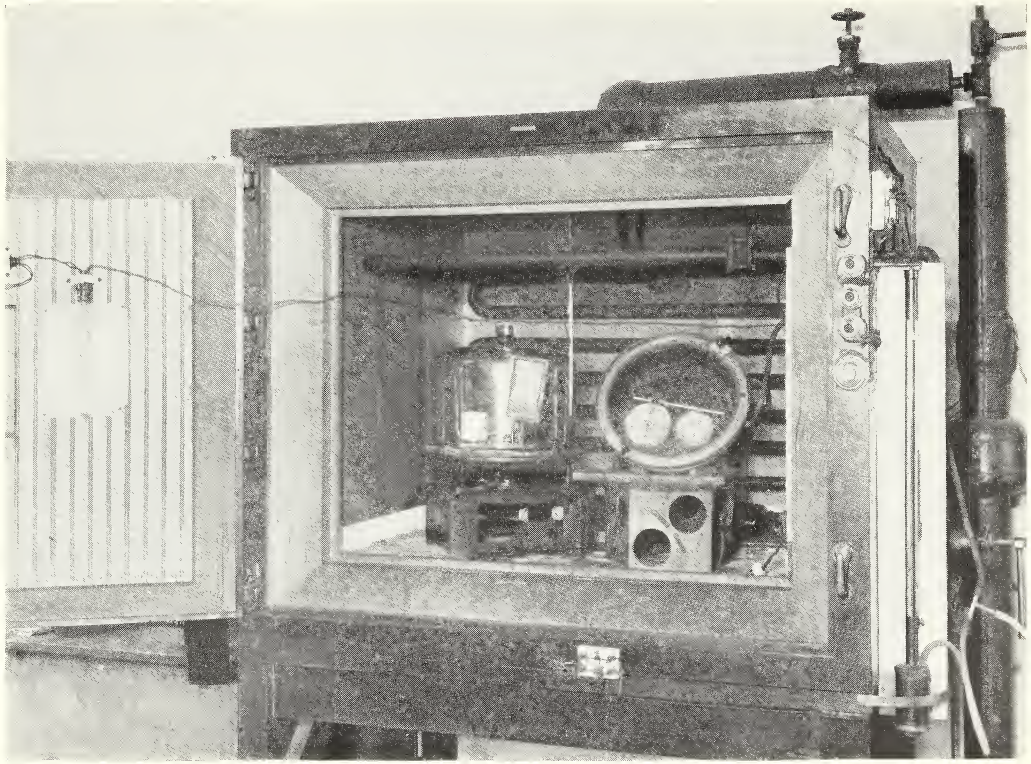

FIG. 4.—*Temperature chamber.*

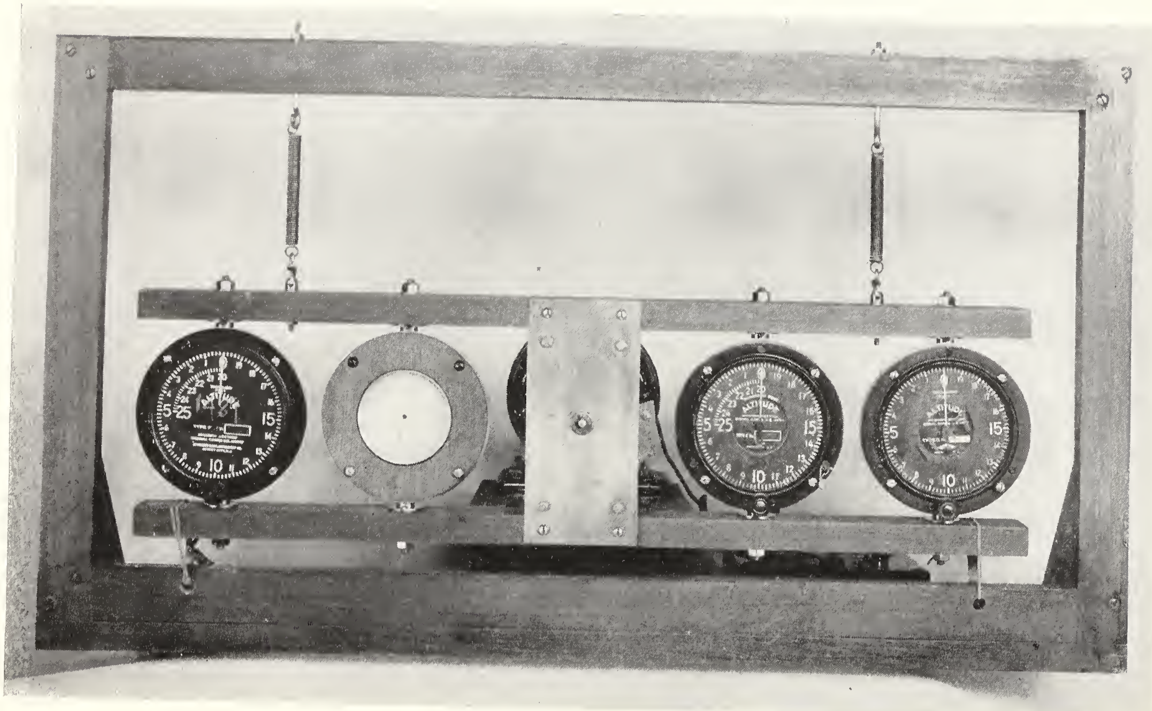

Fig. 5.—*Vibrating board.*

in containers from which the air can be exhausted. Readings are taken through a multiple glass door.

The vibration apparatus as shown in Figure 5 is of special design in that the motor is attached by a flexible coupling to the vibrating frame. This lengthens the life of the motor. The amplitude, frequency, and plane of the vibration can be varied at will, making it possible to subject the instruments to any desired type of vibration.

An optical method of testing the regularity of the motion of the drum of an altigraph is used. This consists of putting a light sensitized sheet of paper on the drum of an altigraph and allowing a very fine line of light to strike the drum parallel to the axis of rotation. If the motion of the drum is regular, the development of the paper should show uniform exposure. If the motion is irregular, the exposure will consist of a series of light and dark strips.

5. TOLERANCES FOR AVIATION ANEROIDS.

Table 2 gives the tolerances for aviation aneroid barometers and barographs. The tolerances are very largely based on the results of the tests made at this bureau on aneroid barometers. Table 3 gives the tolerances for altimeters and altigraphs. These tolerances are, primarily, for instruments with an equally divided altitude scale, but are also applicable to instruments graduated in altitude but with an equally divided pressure scale. Reference to the tolerances has been made in the discussion of the tests.

TABLE 2.—Tolerances for Aviation Aneroid Barometers and Barographs.

Tests.	Data for various ranges, in thousand feet—							
	5	10	15	20	25	30	35	40
Test A:								
End correction—								
Inches of Hg	0.20	0.22	0.26	0.31	0.34	0.36	0.38	0.42
Millimeters of Hg	5.1	5.6	6.6	7.9	8.6	9.1	9.7	10.7
After effect, per cent	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
Test B:								
Change in reading between −10 and +40° C—								
Inches of Hg	.15	.15	.15	.15	.15	.15	.15	.15
Millimeters of Hg	3.8	3.8	3.8	3.8	3.8	3.8	3.8	3.8
Test C:								
Maximum calibration error at 20° C.—								
Inches of Hg	.15	.18	.20	.23	.25	.28	.30	.33
Millimeters of Hg	3.8	4.6	5.1	5.8	6.4	7.1	7.6	8.4
Drift after five hours, per cent	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Average deviation from linear—								
Inches of Hg	.05	.05	.05	.05	.05	.05	.05	.05
Millimeters of Hg	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3
Test D:								
Change per cent of scale value from −10 to +40° C.	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0

TABLE 3.—Tolerances for Altimeters and Altigraphs.

Tests.	Data for various ranges, in thousand feet—							
	5	10	15	20	25	30	35	40
Test A:								
End correction, feet	200	300	400	500	600	750	900	1,100
After effect, per cent	1.5	1.4	1.1	1.1	1.0	0.9	0.9	0.8
Test B:								
Change in reading between −10 and +40° C., feet	150	150	150	150	150	150	150	150
Test C:								
Maximum calibration error at 20° C., feet	150	200	300	350	400	500	650	800
Drift after five hours, per cent	1.1	1.2	1.3	1.5	1.7	1.8	2.0	2.4
Average deviation from linear, feet	60	60	60	60	60	80	100	100
Test D:								
Change per cent of scale value from −10 to +40° C.	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0

6. TOLERANCES FOR ENGINEERING AND SURVEYING ANEROIDS.

The results of the tests for engineering and surveying aneroids are reported on separate forms for each type of instrument. A sample report follows:

B. S. No.: 632.
Name on dial: ——.
Class: II.
B. S. Serial No. 1891.

Case diameter: 4½ inches.
Range: 25–31 inches.
Least reading: 0.005 inch.
(Smallest change intended to be read.)

GENERAL TEST.

The above-described aneroid barometer has been compared with a standard barometer with the following results:

		Corrections to readings at various pressures.		
		Aneroid reading (horizontal).	(8) Fast correction.	(9) Slow correction.
		Inches.		
(1) Average deviation by tapping	0	31	−0.015	−0.030
(2) Shift	0	30	.000	.000
(3) Vertical correction	.03 inch.	29	.000	+ .015
(4) Drift in five hours	1.5 per cent.	28	− .002	+ .028
(5) Calibration deviation	.002	27	− .010	+ .035
(6) Temperature coefficient of reading: +0.0006 inch per °C. +20 to +40° C. −0.0011 inch per °C. +20 to −10° C.		26	− .007	+ .053
(7) Temperature coefficient of scale value: −0.05 per cent per °C.		25	− .002	+ .073

(1) In a properly adjusted aneroid barometer the average deviation by tapping should not exceed twice the "least reading" nor in any case 0.02 inch of mercury. (2) and (3) Neither the shift nor the vertical correction should exceed five times the "least reading" nor in any case 0.05 inch of mercury. (4) The drift should not exceed 1½ per cent. (5) The quantity expressing calibration deviation should not exceed five times the "least reading" nor in any case 0.05 inch of mercury. (6) The temperature coefficient of reading as found in test B should not exceed 0.002 inch of mercury per °C. (7) The temperature coefficient of scale value as found for test D should not exceed one-tenth of 1 per cent per °C. (8) and (9) The numerical value of the correction should in no case exceed 0.10 inch of mercury plus 1/100 the range of the aneroid below 30 inches of mercury.

The "fast corrections" given are the corrections which are to be applied algebraically to the aneroid barometer readings in order to get the true pressures when the pressure is changed continuously at a rate of 1 inch of mercury in five minutes, while the "slow corrections" are corrections to be applied to readings taken at a considerably slower rate. They are computed from the fast corrections by adding to each fast correction the corresponding drift. That is, the "slow correction" for any given reading which is x inches of mercury below the initial pressure is equal to the algebraic sum of the "fast correction" at the point plus x times the percentage drift. The difference between the "slow" and "fast" corrections is a measure of the reliability of the aneroid barometer as an absolute as distinguished from an interpolation instrument. The temperature coefficient of the reading is the increase in the reading of the aneroid barometer at constant pressure per °C. above +20° C.

7. CERTIFICATION OF ANEROID BAROMETERS.

Certificates are issued by the bureau for instruments in which the errors do not exceed the tolerances given above. The relative importance of the errors shown by an instrument depends upon the use to which it is to be put. In absolute altitude determinations of aircraft, the sensitiveness of the indications is of very small moment compared with freedom from elastic errors. On the other hand, for interpolation purposes freedom from elastic errors is a minor consideration, for as soon as reference has been made to the fixed altitudes between which the instrument is carried errors which are uniform cancel out, and the chief limitation in the usefulness of the instrument depends upon its freedom from mechanical irregularities.

Specifically, then, the indications of aircraft instruments should be practically independent of the rate at which the pressure is changed. For most uses they need not be precise, but within suitable limits they must be reliable. Consequently, a fair tolerance may be allowed on the average deviation, but the scale value must be right, and it must stay so under the extreme conditions of climbing speed and of temperature.

In a surveying aneroid, on the other hand, larger elastic errors are permissible as long as the instrument is used only for interpolation purposes, but the irregularities of mechanical action should be extremely small. In other words, high precision of reading is necessary.

III. GENERAL INSTRUCTIONS TO APPLICANTS FOR TESTS.

(a) APPLICATION FOR TEST.

All articles submitted for test should be accompanied by a written request. This request should enumerate the articles, giving the identification marks of each, and should state explicitly the nature of the test desired, as well as the use to which the instrument is to be put, since the degree of accuracy necessary in the test, and in many cases the choice of a suitable method of testing, depends upon this. It is suggested that a prior application be made from two weeks to a month preceding the shipment of the apparatus if it is desired that the test be made promptly when the apparatus is received, inasmuch as regular tests are made in the order in which the applications are received, except as this practice may be varied by grouping similar tests together. This will facilitate the work of the bureau as well as the prompt return of the apparatus. When the test is one regularly provided for in the appended schedules of fees, it may be computed in advance and should be sent at the time the apparatus is shipped.

(b) SHIPPING DIRECTIONS.

Apparatus should be securely packed in cases or packages which will not be broken in transportation and which may be used in returning it to the owner. Transportation charges in both directions are payable by the party requesting the test, and transportation is at his risk. Mercurial barometers should be transported by messengers whenever possible. All packages should be plainly marked with the shipper's name and address and, when convenient, with a list of the contents. Each separate piece of apparatus should be provided with an identification mark or number.

(c) ADDRESS.

Apparatus submitted for test, as well as all correspondence, should be addressed: Director, Bureau of Standards, Washington, D. C.

(d) REMITTANCES.

Fees in accordance with the following schedule should be sent when the apparatus is shipped, or promptly upon receipt of bill. Certificates are not given nor is apparatus returned until the fees due thereon have been received. Remittances may be made by money order or by check drawn to the order of the "Bureau of Standards."

IV. SCHEDULE OF FEES.

[Effective on date of issue.]

SCHEDULE 110.—MERCURIAL BAROMETERS.

CLASS I (PRIMARY STANDARD BAROMETERS).

(*a*) Gas correction and investigation of capillary errors. (Fees determined after correspondence.)

CLASS II (LABORATORY STANDARDS WITH BORE GREATER THAN 1 CM).

(*g*) Calibration with high accuracy	$10. 00
(*h*) Calibration with ordinary accuracy	5. 00
(*i*) Test at one point with ordinary accuracy	3. 00

CLASS III (HIGH ALTITUDE BAROMETERS WITH BORE LESS THAN 1 CM).

(*m*) Calibration with ordinary accuracy	10. 00
(*n*) Test at one point with ordinary accuracy	4. 00

CLASS IV (COMMON BAROMETERS WITH BORE LESS THAN 1 CM).

(*r*) Calibration with high accuracy	7. 50
(*s*) Calibration with ordinary accuracy	5. 00
(*t*) Test at one point with ordinary accuracy	2. 00

SCHEDULE 111.—OTHER MERCURY GAGES.

(Fees determined after correspondence.)

SCHEDULE 112.—ANEROID BAROMETERS.

(*a*) Working or flight-history test. Fees determined after correspondence.

(*b*) Short test for service instruments. Fee one-half that of (*d*) for instrument of equal range.

(*c*) Regular test for weather aneroids, stationary barographs, or other barometers with a total range not exceeding 4 inches (each aneroid) 2. 00

(*d*) General test for all aneroids used in general altitude determination, including pocket size and surveying aneroids, and the altimeters, aerobarographs, and altigraphs employed in aviation:

Range.	Per instrument.	Per dozen (all of same range.)
(1) To 20 inches, or 10,000 feet	$5.00	$40.00
(2) To 15 inches, or 20,000 feet	7.50	60.00
(3) To 10 inches, or 30,000 feet	10.00	80.00
(4) To 5 inches, or 45,000 feet	12.50	100.00

For the testing of barometers to an exceptional degree of accuracy or for calibration a further charge will be made. For testing the scales or thermometers attached to barometers the fees will be in accordance with Circulars Nos. 2 and 8, respectively. For educational and scientific institutions and societies a discount of 50 per cent will be allowed on all tests under the above schedules. Government or State authorities entitled to tests free of charge under the law must make application in writing for each test in order to avail themselves of the privilege.

S. W. STRATTON,
Director.

Approved:

HERBERT HOOVER,
Secretary of Commerce.

V. APPENDIX. TABLE FOR THE GRADUATION OF ALTIMETERS.

The following table for the graduation of altimeters was computed from the formulas:

$$H = 62{,}900 \log_{10} \frac{29.90}{P}$$

$$= 92{,}820 - 62{,}900 \log_{10} P,$$

where H is the altitude in feet, P the barometric pressure in inches of mercury, and

$$H = 62{,}900 \log_{10} \frac{759.6}{P}$$

$$= 181{,}189 - 62{,}900 \log_{10} P,$$

where H is the altitude in feet, and P the barometric pressure in millimeters of mercury.

These formulas are based on the assumption that the air column is at an average temperature of +10° C., and that the corresponding mean humidity conditions prevail. The formulas are calculated from the constants used in the Smithsonian Meteorological Tables Nos. 51 and 54, fourth revised edition, and accordingly the small effect due to the variation of gravity is disregarded.

The corresponding formula for the altitude in meters and for pressures in millimeters of mercury is—

$$H = 19{,}172 \log_{10} \frac{759.6}{P}$$

$$= 55{,}227 - \log_{10} P,$$

where H is the altitude in meters, and P the barometric pressure in millimeters of mercury.

The following table gives the altitude pressure relation for each thousand-foot interval from 0 to 48,000 feet.

Altitude (feet).	Pressure.		Altitude (feet).	Pressure.	
	Inches of mercury.	Millimeters of mercury.		Inches of mercury.	Millimeters of mercury.
0	29.90	759.6	25,000	11.98	304.2
1,000	28.83	732.4	26,000	11.54	293.2
2,000	27.79	706.0	27,000	11.13	282.6
3,000	26.79	680.6	28,000	10.73	272.4
4,000	25.83	656.2	29,000	10.34	262.8
5,000	24.90	632.6	30,000	9.97	253.2
6,000	24.00	609.8	31,000	9.61	244.2
7,000	23.14	587.8	32,000	9.27	235.4
8,000	22.31	566.8	33,000	8.94	227.0
9,000	21.51	546.4	34,000	8.61	218.8
10,000	20.73	526.8	35,000	8.30	211.0
11,000	19.99	507.8	36,000	8.01	203.4
12,000	19.27	489.6	37,000	7.72	196.0
13,000	18.58	472.0	38,000	7.44	189.0
14,000	17.91	455.0	39,000	7.17	182.2
15,000	17.27	438.6	40,000	6.91	175.6
16,000	16.65	422.8	41,000	6.66	169.2
17,000	16.05	407.6	42,000	6.42	163.2
18,000	15.47	393.0	43,000	6.20	157.4
19,000	14.91	378.8	44,000	5.97	151.6
20,000	14.38	365.2	45,000	5.76	146.2
21,000	13.86	352.2	46,000	5.55	141.0
22,000	13.36	339.4	47,000	5.35	136.0
23,000	12.88	327.2	48,000	5.16	131.0
24,000	12.42	315.4			