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BAROMETRY FOR ALTIMETER CALIBRATION

FOREWORD

Changes in the revision are format/editorial only.

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1. SCOPE:

This SAE Aerospace Information Report (AIR) is concerned only with aspects directly relating to available accuracy. While well-designed photoelectric, inductive or capacitive readers and pressure regulators, and other accessories are highly desirable for convenience and production rate, they are considered to be outside the scope of this AIR.

1.1 Purpose:

This AIR is intended to define three classes of barometers, working, reference and transfer, and some aspects of their use so that altimeters and air data transducers calibrated against working barometers will be comparable. An accuracy of ±0.003 inch (or ±0.076 mm) Hg should be approachable with working barometers meeting the recommendations in this AIR.

NOTE: 0.003 inch Hg corresponds to 3 ft of altitude at sea level and 11 ft of altitude at 40,000 feet. (0.076 mm Hg corresponds to 0.8 m of altitude at sea level and 3.4 m of altitude at 12,000 meters.)

2. REFERENCES:

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3. "Barometer, Mercurial, Altitude Test, Type A-1", U.S. Air Force Specification MIL-B-4308B, Amendment 1, Washington, July 1960.

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17. “Barometers, Mercurial, Used in Calibration of Aeronautical Equipment”, U.S. Military Standard MIL-STD-844, Change 1, January 1967.

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20. “Recommendation on Barometry for Altimeter Calibration (ATA 34-10-2)”, Anderson, United Air Lines Engineering Report F-1444, February 1970.

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24. “Barometry”, Stratton, Douglas Aircraft Co., Engineering Department Report SM-23393, Santa Monica, December 1958.

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26. “Pressure Measurement for Pressure Altimetry”, Russell, Federal Aviation Agency Report RD-64-119, Project 320-205-02N, Washington, August 1964 (AD 607246).

27. “Barometric Pressure Standard and Calibration Survey”, Albin, Eclipse-Pioneer Division of Bendix Corp., Report on Project No. 115-22D for FAA, Contract FW-WA-4170, Teterboro, August 1963.

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29. “Tables of Airspeed, Altitude, and Mach Number Based on Latest International Values for Atmospheric Properties and Physical Constants”, Livingston and Gracey, National Aeronautics and Space Administration Technical Note D-822, Washington, August 1961.

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3. DESIGN OF MERCURIAL WORKING BAROMETERS:

3.1 Definition:

A working barometer is one whose normal use is to be connected to one or more altimeters, air data transducers, or other precise absolute pressure devices, and operated with them to the full range of pressures required for their calibration.

3.2 General Construction:

3.2.1 The barometer should be of sturdy construction and of such design that it can be serviced without loss of accuracy in any completely equipped instrument shop, without the use of special jigs or tools.

3.2.2 Parts requiring matching, or parts non-interchangeable between barometers of the same model, should be permanently marked with the serial number of the barometer.

3.3 Tube:

The tube should be of precision-bore glass and should have an internal diameter of at least 0.5 inch (12.7 mm). Preference should be for a larger diameter. The surface tension (capillary) errors of a 0.625 inch (15.875 mm) tube for example, are only about half of those for a 0.5 inch (12.7 mm) tube. The top should be connected to a vacuum pump and gauge.

3.4 Cistern:

3.4.1 The internal diameter of the cistern should be precisely determined and related to the internal diameter of the tube by the scale-shortening factor.

3.4.2 The barometer should be operable to the zero point of the scale (or other readout means) to permit precise determination of the amount of mercury in the barometer while tube and cistern pressures are equal.

3.5 Levelling and Plumbing Provisions:

The base should include levelling screws and bubble levels so that the cistern mercury level and scale (or other readout device) zero may be levelled within 0.001 inch (0.025 mm) and the scale plumbed within 0.5 degrees (0.009 rad) of verticality.

3.6 Mercury:

The mercury should be triple-distilled, bright and shiny, and free from tailing. See also 5.8.

3.7 Thermometer:

A mercurial thermometer, accurate within 0.2 degrees Celsius, should be permanently installed on the barometer in such fashion that the thermal lag of the thermometer and its mounting closely approximate that of the barometer mercury. On a barometer of 60 inches (or 150 cm) or greater nominal range, two or more thermometers should be installed.

3.8 Scale:

3.8.1 Standard conditions for pressure measurement are in terms of mercury at 0 °C (32 °F) and a gravitational acceleration of 980.665 cm/second/second, although a scale may be cut to read in these terms while at other temperatures and gravities.

3.8.2 The scale should be engraved on a single piece of metal whose coefficient of expansion is known and has been taken into account in the design. The primary calibration should be in decimal inches or in millimeters, or in shortened decimal inches or shortened millimeters to account for changes in cistern mercury level, or in millibars or pascals.

NOTE: 1 pascal = 1 newton/meter^2 (exactly)
= 0.01 millibar (exactly)

3.8.3 If an altitude scale is also provided, it should be cut in accordance with the U.S. Standard Atmosphere of 1962. Within the range of concern of this AIR this is identical to the ICAO Standard Atmosphere. The altitude should be in terms of geopotential feet.

3.8.4 Unless the barometer is designed for single-temperature operation and housed in an enclosure whose temperature is precisely controlled, means should be provided for the temperature correction to be applied to the reading. Unless the barometer is designed for a particular location, means should be provided for the gravity (latitude) correction to be applied to the reading. Means should be provided to indicate at all times the amounts of compensation being applied for temperature and for gravity.

3.8.5 A scale cut for use only at a specific temperature and/or a specific value of gravity should be permanently marked with those values.

3.8.6 The scale should be permanently marked with the serial number of the barometer.

3.9 Other Readout Means:

3.9.1 In lieu of, or in addition to the scale, a lead screw and turns-counting device, a metallic tape, or other equivalent readout means may be provided. Barometers of this type should have provisions for checking the accuracy and wear of the readout means by the use of gauge blocks, unless a scale complying with 3.8 is also permanently fitted.

3.9.2 Unless the barometer is designed for single-temperature operation and housed in an enclosure whose temperature is precisely controlled, means should be provided for the temperature correction to be applied to the reading. Unless the barometer is designed for a particular location, means should be provided for the gravity (latitude) correction to be applied to the reading. Means should be provided to indicate at all times the amount of compensation being applied for temperature and gravity.

3.9.3 A readout assembly designed for use only at a specific temperature and a specific value of gravity should be permanently marked with those values. Any portions of the assembly peculiar to such values should also be so marked.

3.10 Reading Device:

3.10.1 Crosshairs, a sighting ring, or other arrangement should be provided so that the position of the meniscus in the tube can be precisely located. The reading device should be capable of going to the zero point of the scale (or other readout means) to allow accurate determination of the amount of mercury in the barometer while the tube and cistern pressures are equalized.

3.10.2 In a barometer fitted with a scale, the reading device should include a vernier allowing reading of the scale to 0.001 inch or 0.02 mm.

3.11 Certification:

The manufacturer should furnish with each barometer a calibration chart showing the residual errors of the barometer. This should have been made by comparison with his Master, which should have been calibrated by the National Bureau of Standards.

3.12 Instructions:

3.12.1 The manufacturer should furnish with each barometer complete and fully illustrated instructions for assembly, operation, disassembly, cleaning, and servicing. The instructions should fully detail all the potential sources of error and the means of avoiding them.

3.12.2 The instructions should include statements as to:

a. The scale-shortening ratio.

b. Temperature and gravity values at which, without compensation, the scale (or other readout means) will read in standard terms; i.e., 0 °C and 980.665 cm/second/second.

c. Standard Atmosphere used.

d. Means of avoiding or correcting capillary depression.

e. Other significant corrections and assumptions used.

3.12.3 The format of the instructions should be in accordance with Air Transport Association of America Specification 100 (Reference 4).

3.13 Parts:

3.13.1 The manufacturer should furnish with each barometer a complete parts list, and should carry in stock for immediate delivery gaskets, packings, tubes, cisterns, and any other parts or assemblies likely to require replacement.

3.13.2 The format of the parts list should be in accordance with Air Transport Association of America Specification 100 (Reference 4).

4. DESIGN OF MERCURIAL REFERENCE BAROMETERS:

4.1 Definition:

A mercurial reference barometer is one whose normal use is to monitor the calibration of working barometers, whose design is such that its own calibration may be established by direct linear measurement of the height of the mercury column, whose design includes refinements to optimize accuracy (at the expense of convenience if necessary), and which is isolated insofar as possible from common sources of error with the working barometers. An accuracy of 0.001 inch (0.025 mm) should be sought.

4.2 General Construction:

In construction, maintainability, and identification of non-interchangeable parts, a reference barometer should meet the same requirements as a working barometer.

4.3 Tube:

The internal diameter of the tube should be at least 0.75 inch (or 20 mm). Preference should be for a larger diameter, say, 1.0 inch (25.4 mm) to minimize surface tension (capillary) errors. If the scale includes millibars, pascals, shortened inches or shortened millimeters as well as true, the tube should be of precision-bore glass. The top should be connected to a vacuum pump and McLeod type gauge. The pump and gauge should be connected only to the reference barometer, and not manifolded with any other.

4.4 Cistern:

4.4.1 If the scale includes millibars, pascals, shortened inches or shortened millimeters as well as true, the internal diameter of the cistern should be precisely determined and related to the internal diameter of the tube by the scale-shortening factor.

4.4.2 The cistern should include a pointer to indicate the precise level of the mercury surface. If the barometer is of the variable cistern (Fortin) type the pointer should be fixed at the zero of the scale. If the barometer is of the fixed cistern type, the pointer should be mounted on a micrometer head so that the distance of the mercury surface in the cistern from the zero of the scale may be measured. The barometer should be operable to the zero point of the scale, so that when the tube and cistern pressures are equal, the height of the pointer with respect to the zero may be established.

4.5 Levelling Provisions:

The levelling provisions should be at least equal to those for working barometers.

4.6 Mercury:

The purity and cleanliness of the mercury should be at least equal to that for working barometers.

4.7 Thermometer:

A mercurial thermometer, accurate within 0.1 degree Celsius, should be permanently installed on the barometer in such fashion that the thermal lag of the thermometer and its mounting closely approximate that of the barometer mercury. On a barometer of 60 inches (or 150 cm) or greater nominal range, two or more thermometers should be installed.

4.8 Scale:

4.8.1 The principal calibration of the scale should be in inches or millimeters, true at the same temperature at which the gauge block set is true. Secondary calibration in shortened inches, shortened millimeters, or in millibars or pascals may also be provided.

4.8.2 At the zero point of the scale there should be a base upon which gauge blocks can be stacked.

4.8.3 In other respects the scale should at least equal the requirements for working barometers, except that instead of a compensating device, charts may be used to apply temperature and gravity corrections.

4.9 Reading Device:

The crosshairs, sighting ring, or other arrangement should allow direct visual observation of the top of a stack of gauge blocks as well as the top of the mercury column. In other respects the reading device should at least meet the same requirements as for a working barometer.

4.10 Certification:

The certification procedure for a reference barometer should at least equal that for a working barometer.

4.11 Instructions:

The instructions furnished with a reference barometer should at least equal those for a working barometer.

4.12 Parts:

The availability of parts for a reference barometer should at least equal that for a working barometer.

5. INSTALLATION AND OPERATION OF MERCURIAL BAROMETERS:

5.1 General:

In order to obtain the best accuracy from a barometer the manufacturer's recommendations should be carefully followed. In addition the following (most of which should be included in the manufacturer's instructions) should also be observed:

5.2 Temperature:

5.2.1 A barometer provided with a temperature-compensation device (as distinct from one installed in a temperature-controlled cabinet) should be installed in a room whose temperature is controlled within ±2 °C (±3.6 °F) or closer, including nights and weekends. After any larger change in room temperature, the barometer should be allowed 3 to 12 hours or more to stabilize, according to the magnitude of the change, before being used for altimeter calibration.

5.2.2 If close control of room temperature cannot be assured, the barometer should be installed in a temperature-controlled cabinet; a fan should be provided to minimize vertical temperature gradients.

5.3 Tube Pressure:

The use of a continuous-operation vacuum pump and a vacuum gauge is essential. Each working barometer should have its gauge read daily to assure that the absolute pressure in the tube is less than 15 microns mercury (0.0006 inch Hg or 0.015 mm Hg). Each reference barometer, when in use, should have its gauge read to assure that the absolute pressure in the tube is 5 microns mercury (0.0002 inch Hg or 0.005 mm Hg) or less.

5.4 Vibration:

It is advisable to vibrate or tap a barometer tube before reading unless the tube diameter is over 1 inch (25.4 mm). Surface tension effects, particularly if the glass or mercury is even slightly fouled, may cause the barometer to read as if it were subject to friction or hysteresis errors.

5.5 Fouling of Mercury and Glass:

Suitable precautions should be taken to minimize fouling of the mercury and glass. The air used to relieve the cistern vacuum, as when returning to ambient pressure from altitude, should be dried and filtered. Dry nitrogen is better.

NOTE: Where a filter-desiccator arrangement is used, it should be placed in the relief line feeding into the system as close to the cistern as practicable. The air flow from the testing chamber to the vacuum pump should not pass through the filter-desiccator, as this will shorten the intervals at which it must be serviced.

When a barometer is to be left idle, as over a weekend or holiday, leaving it pressurized to, say, 32 inches (or 812 mm) will help avoid the formation of rings in the part of the tube where most readings are taken.

5.6 Pressure Connections:

Lines connecting barometers to other equipment should be of glass, stainless steel, or an elastomer known to be impermeable to air and water, sulfur-free and otherwise inert to mercury. The lengths of elastomer should be minimized.

NOTE: Rubber or neoprene hose and tubing may contain powdered talc or soapstone; this should be completely removed before use.

5.7 Pumping System:

5.7.1 Suitable precautions should be taken to prevent oil or oil vapor from reaching the top of the barometer tube.

5.7.2 The discharge of the vacuum pump should be connected to a line or exhaust duct to open air, as the discharge may contain significant amounts of oil and mercury vapors.

5.8 Cleaning:

When the mercury or the glass parts of the barometer have become fouled as evidenced by discoloration, scum, or ragged meniscus formation in the tube or cistern, the barometer should be cleaned and the mercury replaced in accordance with the manufacturer's instructions. The mercury should be equal to that furnished with new barometers.

NOTE: The following procedure is suggested for cleaning glass parts: Scrub with hot water, detergent, and a soft bristle brush. Rinse with hot tap water. Wash with warm 50 to 60 °C (122 to 140 °F) chromic acid cleaning solution. Rinse with tap water. Wash with dilute nitric acid. Rinse with tap water. Rinse with distilled water several times. Dry with heat and/or vacuum.

5.9 Mercury:

5.9.1 The mercury used to refill the barometer should be equal to that specified for original installation (see 3.6). It should have a bright, mirrorlike surface, and be free from film or scum. It should pour freely from a thoroughly clean, dry, glass container without leaving any mercury adhering to the glass (References 5, 6, and 7).

NOTES: To prepare a beaker or other vessel for this test, it should be cleaned and dried according to the same procedure recommended for barometer tubes and cisterns, then wiped out with a little of the mercury to be tested and (rice) lens paper.

Properly applied, the "pours-without-tailing" test assures that the base metal contamination is less than one part per million.

5.9.2 To avoid entrapment of air while filling a newly cleaned barometer, it should be evacuated to 15 microns and the mercury drawn into the cistern from a supply bottle through a filler tube whose entry is kept clear of both the surface and bottom of the mercury.

5.9.3 Suitable precautions should be observed while handling mercury because it is highly toxic in both liquid and vapor phases. No attempt to clean it or distill it should be made in the instrument shop.

NOTES: Any mercury spilled while draining and filling the barometer should be gathered up at once to prevent its becoming “floured”; that is, subdivided into tiny droplets which are prevented from recoalescing by dust particles, etc., and then, having lost the appearance of mercury, become spread about with any ambient dirt. It is advisable to have available an assembly consisting of a small hose and nozzle and water-trap which may be connected to a vacuum line. General purpose vacuum cleaners are not suitable.

The hands should be washed carefully after handling mercury, even though no obvious contact has occurred.

Mercury and food should never be handled in the same area.

Mercury removed from barometers should be returned for credit or for distillation. Cleaning and distillation of mercury should be done only in a suitably equipped refining plant or chemical laboratory. Mercury should be stored in glass containers.

For additional information on the handling of mercury, References 5 through 12 should be consulted.

5.10 Log:

A log should be kept of each individual barometer, recording installation, cleaning, adjustments, and other work done.

5.11 Ambient Pressure Measurement:

5.11.1 Where a barometer is used only for altimeter calibration, the slight pressurization of the shop area by air-conditioning equipment has no effect. If, however, a barometer in a pressurized room is to be used for computation of the Altimeter Setting QNH, or for comparison with Weather Bureau or other barometers in terms of QFE, QFF, or QNE, there should be provisions for connecting the cistern to a pressure-tight line leading to a static port outside of the building. Reference 2 gives construction details.

5.11.2 Definitions and procedures for computation of QFE, QFF, QNE, and QNH can be found in References 2 and 13.

5.11.3 For QNH computations and for comparisons, it is essential to know the height of the barometer(s). In order to make clear the relationships between the elevations and reference planes which need to be known, it is suggested that a diagram similar to Figure 1 be made. Mean Sea Level is the basic reference for altimetry as well as for surveying. Mean Low Water, Mean Lower Low Water, etc., are of no interest in altimetry, but should be noted, if only to avoid confusion in terminology.

5.11.4 Where comparisons are made with Weather Bureau barometers, it should be recognized that because of geographical separation and the local pressure effects of winds, this kind of comparison is useful only for detecting gross errors.

Some Weather Bureau stations use a reference elevation, that for historical continuity of records, is not the actual elevation of the barometer cistern. Arrangements should be made with the Senior Meteorologist to assure that all applicable corrections are applied so that the readings may be comparable, and that a mutually convenient schedule has been set up for simultaneous readings.

6. DESIGN OF NON-MERCURIAL WORKING BAROMETERS:

6.1 Description:

Barometers may be constructed using means other than the weight of a column of mercury to establish a pressure accurately. They may be categorized broadly into those using a gravity reference and those using a spring force reference.

6.1.1 Non-mercurial gravity reference barometers are in their most usual form piston gauges, wherein a precisely known weight acting upon a piston of precisely known area and low friction accurately determine a pressure.

6.1.2 Non-mercurial spring force reference barometers are in their most usual form dependent upon the elasticity of a Bourdon tube or helix of quartz or other material of low hysteresis and great stability. Capsules of silicon whose deflection is measured by a strain gauge directly deposited upon the surface, and metal capsules whose resonant frequency varies with pressure are also being developed for this purpose.

6.2 Application:

There is no objection to use of non-mercurial barometers for altimeter or air data computer calibration, although those of the spring force type may require more frequency comparison to a reference barometer than gravity reference types.

7. DESIGN OF NON-MERCURIAL REFERENCE BAROMETERS:

7.1 Description:

Reference barometers may also be of non-mercurial design, although with certain qualifications related to long-term stability.

7.2 Application:

7.2.1 Non-mercurial barometers of the gravity reference or piston gauge type may be used as reference barometers provided they are arranged for direct application of the dead-weight to the piston, without intervening mechanism, such as balance beams or interpolating devices.