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### PART 2: SECTION 2

#### CHAPTER 2

## ALTIMETERS

### Purpose

1. The function of an altimeter is to indicate the height of an aircraft above a pre-set datum, usually sea level.

### Implementation

2. Pressure altimeters measure atmospheric pressure and register it against a height scale. They are, in fact, aneroid barometers graduated to indicate against a height scale instead of against a barometric pressure scale.

3. Air has weight and therefore exerts a pressure, known as atmospheric pressure. At any point on the earth's surface the atmospheric pressure is equivalent to the pressure exerted by a column of air approximately fifty miles high, and it can be expressed in various units, *e.g.* millibars, pounds per square inch, or as the height of a column of mercury or water which that air pressure would support.

4. As an aircraft climbs away from the earth's surface the height of the column of air above it, and therefore the weight and pressure exerted by that column, decreases. That is to say, atmospheric pressure decreases with height. Therefore if the atmospheric pressure at sea level and the rate of decrease of that pressure with height are known, a knowledge of the pressure existing at any point above sea level enables the altitude above sea level of that point to be established. In this connection, a practical approximation is that a decrease in pressure of one millibar is roughly equivalent to an increase in height of 30 feet.

5. With the exception of the Mk. 13 (Simple Altimeter) scale markings, the altitude graduations on pressure altimeters in service use are spaced according to the calibration law of the International Convention for Aerial Navigation, or I.C.A.N. Law, which assumes a mean sea level barometric pressure of 1013.2 millibars and a temperature of 15°C. at that level, with a temperature lapse rate of 1.98°C. per 1,000 feet up to an altitude of 36,090 feet, above which the temperature is assumed to remain constant at -56.5°C. When the conditions experienced differ from these standards, corrections must be applied in order to compute true height.

6. Not all altimeters in service use are pressure-operated, but this chapter is only concerned with those that are.

### Simple Altimeters

7. A description of a simple altimeter is included in this chapter as an intermediate step to facilitate understanding of the more complex developments of the instrument.

8. The instrument is housed in an air-tight metal case, the interior of which is kept at atmospheric pressure by a tube connecting it to the A.S.I. static line. Inside the instrument case a partially evacuated aneroid capsule is secured at the centre of one of its faces to a base rigidly fixed to the casing. It is prevented from collapsing under the surrounding atmospheric pressure by a strong leaf spring, as shown in Fig. 1.

9. As the aircraft gains height, decreasing atmospheric pressure allows the spring to pull the capsule faces further apart. This movement is considerably magnified by a system of levers and is communicated to a pointer which moves around a graduated card. A bimetallic bar in the transmission compensates for variations in the temperature characteristics of the capsule and leaf spring. This type of altimeter (Mk. 13 Series) is calibrated according to the Isothermal Law which assumes a constant temperature of 10°C. at all heights. Consequently, large corrections become necessary at high altitudes; they are determined by use of an isothermally calibrated computer.

10. In the type of simple altimeter shown in Fig. 1, the graduated dial card can be rotated by a knob, enabling any desired height to be set against the pointer. Before taking off, a pilot using this type of altimeter rotates the graduated dial card until the pointer indicates aerodrome height. Thereafter the pointer continues to indicate height above mean sea level during flight. If, however, owing to a change in the local barometric pressure or temperature at the time of landing, the pointer were to indicate other than aerodrome height, the pilot would rotate the dial card until the pointer again indicated aerodrome height.

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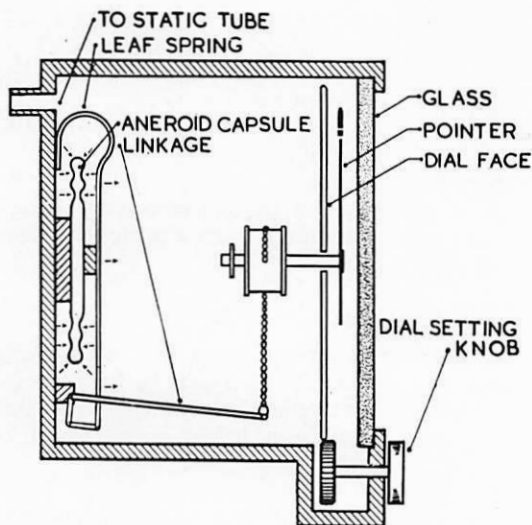
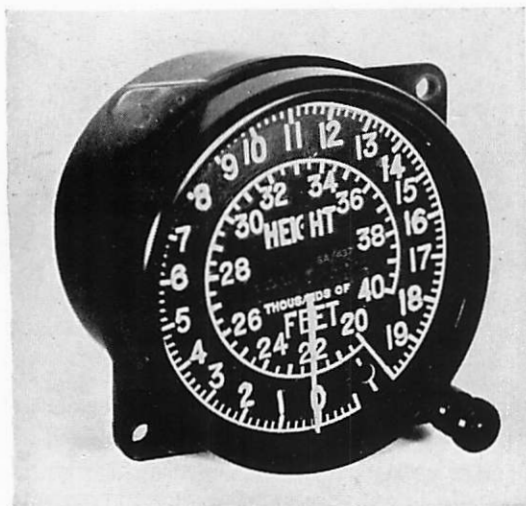


Fig. 1. Simple Altimeter.

### Sensitive Altimeters

11. The sensitive altimeter, designed to register small changes of height, differs considerably from the simple altimeter. Multiple capsules impart to the transmission a wider range of movement which is amplified by a chain of levers and gears, and jewelled bearings are used to minimize friction. The dial (Fig. 2) calibrated from 0 to 9, is swept by three pointers of different lengths. The longest pointer rotates once per 1,000 feet and is geared to the other pointers in the ratio of 10 to 1, and 100 to 1. Thus the figures represent hundreds of feet for the long pointer, thousands for the intermediate, and tens of thousands for the short pointer. As the scale is divided every twenty feet, and the long pointer reacts to changes of

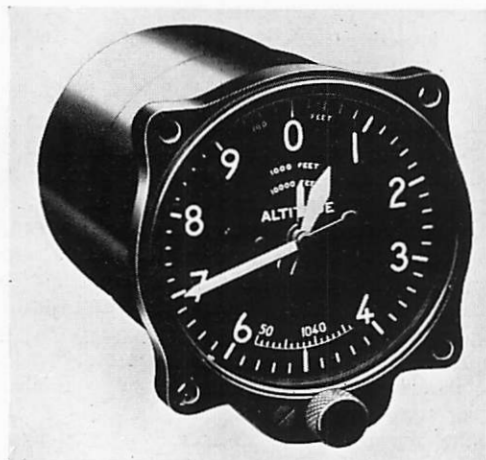


Fig. 2. Sensitive Altimeter, r1k. 14.

ten feet or less, the instrument provides valuable assistance in precision flying. It should be noted, however, that this high degree of sensitivity does not imply a similar standard of accuracy.

12. Fig. 2 shows a small window at the bottom of the dial of the sensitive altimeter. The barometric scale visible through the window is graduated in millibars (occasionally in inches of mercury), and the scale setting is adjusted by a pressure-setting knob at the base of the instrument. The scale links with the height-indicating mechanism so that it registers the atmospheric pressure in the vicinity of the aircraft when the height pointers are set to register zero by means of the pressure-setting knob. Similarly, if the local atmospheric pressure were 1013 millibars and if the pressure-setting knob were turned to set this pressure on the barometric scale the altimeter would register zero feet.

13. If, however, the scale were turned to 1023 millibars under the above conditions, the height pointer would move round to indicate 300 feet, assuming 1 mb. = 30 feet; but were the atmospheric pressure then to rise to 1023 millibars, the pointer would return to zero. It follows that an altimeter set to aerodrome pressure (QFE) registers zero height at aerodrome level and indicates height above the aerodrome during flight; but an altimeter set to mean sea level pressure (QNH) while the aircraft in which it is fitted is on the ground indicates the height of that ground above mean sea level, and during subsequent flight indicates height above the (sea level) datum.

14. The high altitudes and rapid rates of climb and descent associated with jet aircraft have revealed that altimeters having presentations similar to that of the Mk. 14 (Fig. 2) can easily be misread. For example, 21,000 feet can be mistaken for 11,000 feet, or even 1,100 feet. To reduce the possibility of misreading, the shortest (tens of thousands) pointer of the Mk. 14A\*, Mk. 19, and Mk. 20 models (Fig. 3) has an arrow head at its top, the intermediate (thousands) pointer has a circle interposed in its length, while the longest (hundreds) pointer is unchanged from the form shown in Fig. 2.

15. Another disadvantage of the Mk. 14 type altimeter (Fig. 2) is the difficulty experienced in reading and setting the millibar sub-scale. To overcome this, the Mk. 19 and Mk. 20 models have the millibar value presented on a veeder counter (Fig. 3).



Fig. 3. Mk. 20C(P) Altimeter.

16. Constructional details of altimeters are given in A.P. 1275B, Instrument Manual (Navigation Instruments).

### Errors

17. Pressure altimeters are subject to barometric, temperature, instrument, pressure, and lag errors; the last three of these being inherent in the instrument and installation. Blockage of the static tube or vent followed by a change of altitude also causes erroneous indications. Instrument and pressure errors have to be taken into account. The altimeter reads high whenever

the A.S.I. reads high (P.E.C. negative), and vice versa, to an extent which varies with speed. At sea level the relationship between the required correction to the altimeter in feet and the A.S.I. P.E.C. in knots is approximately:—

I.A.S. knots	Altimeter Correction in feet
220	A.S.I. P.E.C. in knots $\times$ 18
300	A.S.I. P.E.C. in knots $\times$ 30
400	A.S.I. P.E.C. in knots $\times$ 43

18. **Barometric Error.** In para. 5 it is stated that pressure altimeters other than those of the Mk. 13 series are calibrated according to the I.C.A.N. Law which assumes, among other things, a mean sea level pressure of 1013.2 millibars. This standard pressure does not often exist at sea level, however, and variation from it would, if no correction for it were made, result in erroneous indications of height. For example, a mean sea level pressure of 1003.2 millibars would, if no correction for it were made, cause the altimeter to indicate a height of 300 feet above sea level. Correction for local barometric pressure variation from the I.C.A.N. standard is therefore made by setting the former on the sub-scale or veeder counter before flight. However, an altimeter correctly set before flight does not continue to indicate height correctly if the aircraft flies into a region of different barometric pressures, or if on return to base a pressure exists different from that set before take-off on the sub-scale or veeder counter. A fall of 10 millibars during a local flight, for example, would mean that an altimeter set to 0 feet at take-off would still register a height of about 300 feet after landing. Similarly, during a cross-country flight into a region of lower pressure, an indication higher than the true altitude would be given, and vice versa. Therefore when the pressure is falling, cross-country flights must be flown with an ample margin of height over the highest ground likely to be encountered (see Fig. 4). Barometric error is eliminated from the sensitive altimeter during local flying by setting the airfield QNH on the barometric pressure sub-scale or veeder counter before taking off, and by resetting, if necessary, before landing. During transit flights, however, all aircraft flying above the lowest quadrantal height are required to have their sub-scale or veeder counters set to the appropriate regional pressure setting. QNH represents the pressure value at which the altimeter sub-scale or veeder counter must be set to ensure that the altimeter will indicate the actual runway elevation on landing.

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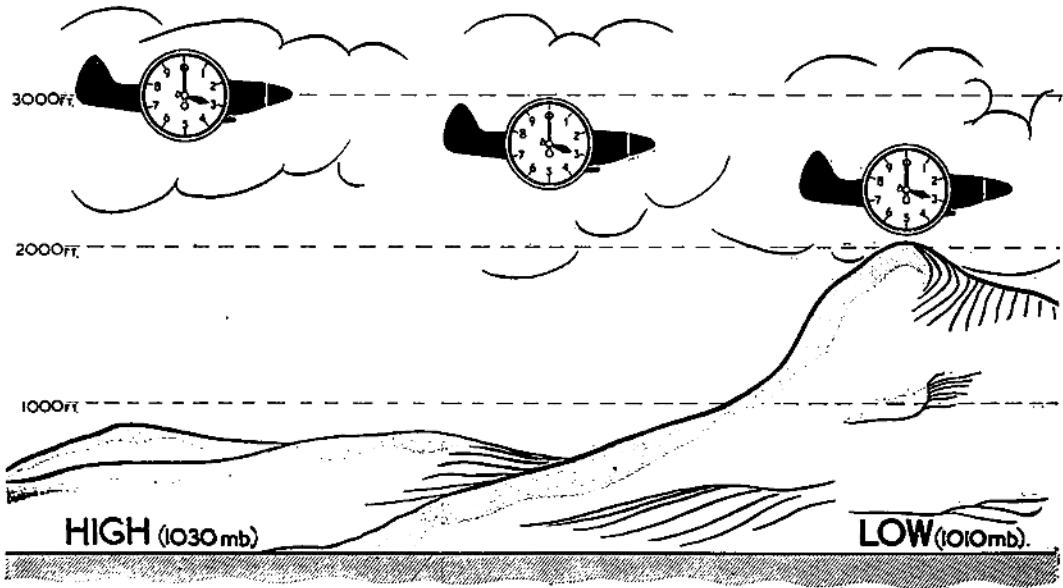


Fig. 4. Effect of Barometric Error.

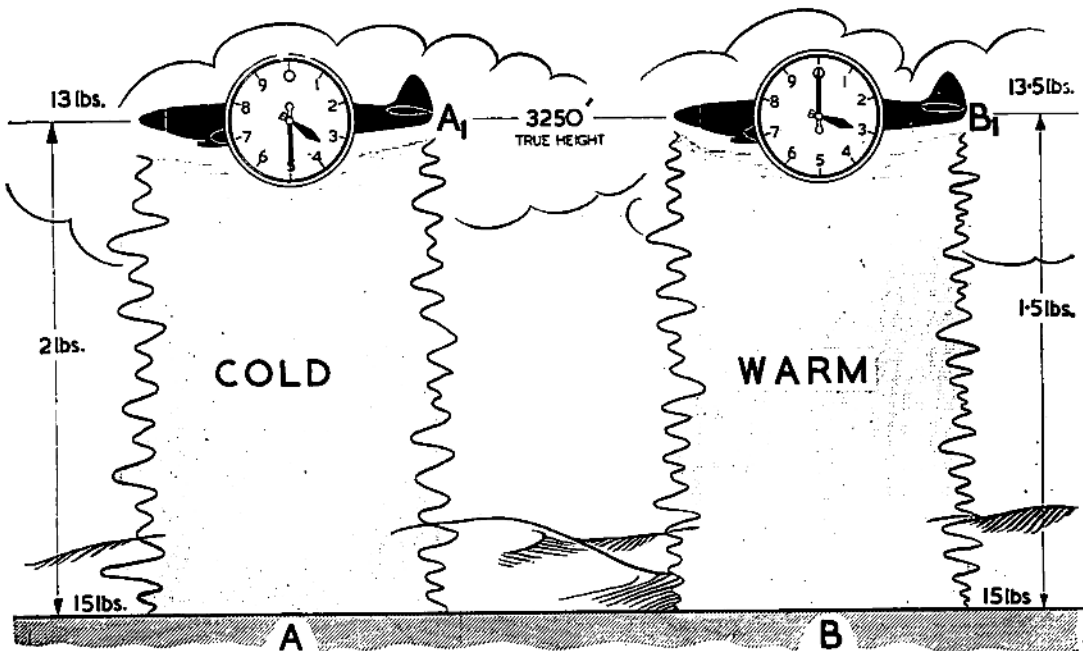


Fig. 5. Effect of Temperature Error.

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19. **Temperature Error.** If under actual flying conditions the temperature lapse rate differs from the I.C.A.N. standard atmosphere for which pressure altimeters are calibrated, a discrepancy known as temperature error occurs. A correction for this error can be made on the height and T.A.S. computer to enable true height to be calculated. A practical example of the cause and effect of this error is shown in Fig. 5, where it is assumed that points A and B are at sea level and have the same sea-level pressure; *i.e.* that the air column above each place exerts a pressure of 15 lb./sq. in. Since variations in temperature cause differences of density and the air above point A is colder than that above point B, the column of air A-A1 must be denser and heavier than the column B-B1. As the ground level pressures at A and B are the same, it follows that the pressure at A1 must be less than that at B1, in this case 13 lb./sq. in. as against 13.5 lb./sq. in. at B1. The pressure drop of 2 lb./sq. in. between A and A1, and 1.5 lb./sq. in. between B and B1, illustrates the fact that pressure decreases more rapidly with height in cold air than in warm. It is thus seen that, relative to the air temperature conditions for which it is calibrated, an altimeter reads higher in colder air and lower in warmer air.

20. **Instrument Error.** Since capsule expansion and contraction are necessarily greatly magnified to indicate against a legible scale, it is impossible to avoid magnifying minute irregularities in the action of the capsules. For this reason, the sensitive altimeter is not as accurate as it is sensitive; see the tolerances listed in A.P. 1275B, Vol. 1, where an allowance of +30/-45 feet at zero increases to  $\pm 350$  feet at 30,000 feet. Simple altimeters are allowed wider tolerances.

21. **Pressure Error.** In the past, pressure error was known as position error and reference to it by that name may still be found in old publications. This is the error due to false static pressure in the immediate vicinity of an aircraft in flight. An aircraft in flight causes a disturbance which alters the static pressure around it and the erroneous representation of static pressure thus communicated to the altimeter is further influenced by the *location* of the point from which the static pressure is obtained as well as by the attitude of the aircraft. The effect of pressure error on altimeter behaviour can be observed during take-off and landing, although the secondary importance of the altimeter at such times rules out the question of correction. In most aircraft, pressure error is

negligible during normal flight at low altitudes, especially in installations using static vents, but becomes significant at high altitudes and mach numbers, where considerable errors may occur.

22. **Lag Errors.** When height is increased or reduced rapidly the altimeter needle lags, causing an under-reading or over-reading respectively, and pilots should allow for this in order to level out at a specific altitude following a climb or dive. The degree of lag is proportional to the rate of change of altitude, and is therefore of the same value for a piston-engined aircraft descending at, say, 5,000 feet per minute as for a jet aircraft losing height at the same rate.

For some time after a rapid descent from high altitude the altimeter may over-read by as much as 200 feet.

23. **Blockage Errors.** Should the static tube or vent become blocked by ice or other obstruction, pressure within the instrument case will remain constant and the altimeter will continue to register the height at which the obstruction occurred. For this contingency an alternative source of static supply is provided on some aircraft, usually inside the fuselage. Unfortunately the pressure so obtained differs to some degree from the external atmospheric pressure, and is influenced by the opening of hoods or windows. A correction for pressure error is therefore necessary when using this internal vent.

#### Pilot's Serviceability Checks

24. In the absence of obvious faults in an altimeter, such as sticking or grossly abnormal behaviour, a pilot may assume it to be serviceable if, when aerodrome level barometric pressure is set on the millibar scale or veeder counter, the pointers register zero within +30/-45 feet. When setting the altimeter, however, the pilot should note any error between the indicated and known airfield height when applying the setting to the barometric scale. He should then turn the scale until the instrument indicates the known airfield height, note the correction required to be made on the scale, and apply this correction to any new altimeter setting given while in flight. Note that instrument error alters as the metal capsules age.

#### Emergency Static Supply Source

25. If the normal static source becomes blocked by ice or by a foreign body the altimeter can be brought back into operation, even when no alternative source of static pressure is fitted to

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the aircraft, by carefully breaking the glass cover plate of one of the pressure instruments. This enables cockpit pressure to be used in place of static pressure from the normal source. In such an emergency in a jet aircraft the least useful instrument is the machmeter, while in aircraft without machmeters the least useful instrument is the rate of climb and descent indicator. A large pressure error will follow this action; there is therefore little to recommend it unless some sort of reading, however much in error, is essential. The cockpit must be unpressurized before taking a reading from the altimeter in these circumstances. Even with a low airspeed, 200 knots or less, the pressure error will cause an over-reading of at least 300 feet.

### Contacting Altimeters

26. **Purpose.** The purpose of a contacting altimeter is to give an audible or visual warning to a pilot of his approach to, and arrival at, a

pre-selected height. This instrument is particularly useful during dive-bombing, since its use obviates the necessity for the pilot continually having to watch both the target and the aircraft altimeter during the dive. Thus the pilot can concentrate to a greater degree upon accurate target sighting.

27. **Implementation.** The contacting altimeter works partly on the same principle as the pressure altimeter, *i.e.* it has an evacuated capsule which expands under the influence of reduced atmospheric pressure and contracts during descent, but the capsule has the additional function of controlling the position of a glass pin. This in turn regulates the completion of an electric circuit which gives a warning to the pilot whenever a pre-selected height is approached during descent and breaks the warning operating circuit when the pre-selected height is reached.

28. The mechanism of this instrument is described in A.P. 1275B.

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