PART 2 : SECTION 6

CHAPTER 3

# THERMOMETERS

## Purpose

1. There are three temperatures of which the pilot must be kept informed : namely, the outside air, engine oil, and (depending on the type of power unit) the radiator, cylinder head, or jet pipe temperatures. A knowledge of the outside air temperature is required in the application of correction to indicated heights and airspeeds and to show when there is a possibility of airframe or carburettor icing. The engine temperature gauges not only help the pilot to operate his engines efficiently, but also provide timely warning of conditions likely to lead to damage or failure.

## Implementation

2. Nearly all thermometers or temperature gauges employ an element of which the physical or electrical properties alter more or less proportionately with the temperature, those installed in aircraft depending on the following variations :—

(*a*) The volume of a quantity of mercury.

(*b*) The vapour pressure of a volatile liquid, *e.g.* ether.

(*c*) The electrical resistance of certain metals.

(*d*) The current generated by a thermo-couple.

(*e*) The shape of a bi-metallic element.

## CONSTRUCTION AND OPERATION

3. Representative types of thermometers are described below in broad outline. Constructional details are given in A.P. 1275A.

## Non-Electrical Thermometers

4. **Mercury Type.** This consists of a steel bulb connected by a length of capillary tubing to a Bourdon tube gauge, the system being filled with mercury. Expansion of the mercury with a rise in temperature dilates the Bourdon tube and actuates the indicating pointer, which registers against a graduated scale. When used as an air thermometer the bulb is usually located on the underside of the aircraft and is shielded from the direct rays of the sun. For oil temperature measurement the bulb is immersed at the engine oil inlet. To avoid errors due to a difference in temperature between the Bourdon and capillary tubes on the one hand and the bulb on the other, the capacity of the bulb is made large relative to that of the tubing, and a small bi-metallic compensating element is incorporated between the Bourdon tube and pointer spindle.

5. **Vapour Pressure Type.** Used for measuring the coolant temperature in liquid-cooled engines, the vapour pressure thermometer is superficially similar to the mercury type, but the Bourdon tube is actuated by variations in pressure instead of volume. The copper or brass bulb, which is immersed in coolant at the hottest part of the system, is filled with ether, about half being liquid and the rest vapour. The capillary tube (which projects well down into the bulb) and the Bourdon tube are completely filled with liquid ether. When the temperature of the bulb rises some of the liquid ether is vaporized, and the pressure in the bulb is thus increased and dilates the Bourdon tube, causing pointer movement.


Fig. 1. Bi-Metallic Thermometer.

6. **Bi-Metallic Type.** This is a direct-reading outside air temperature thermometer (Fig. 1) usually fitted at the bomb aimer's position. Projecting back from the instrument case is a metal tube (Fig. 2) enclosing the helical heat-sensitive element. The element comprises two metals having different coefficients of expansion, one welded outside the other, so that the helix tends to wind or unwind with temperature changes. One end of the element is fixed and the other attached to a cranked spindle on which is mounted the pointer.

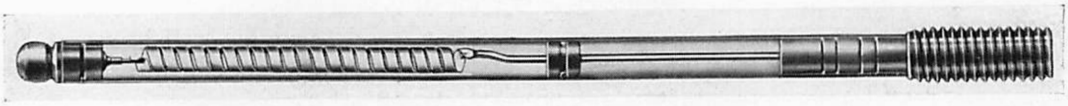


Fig. 2. Bi-Metallic Thermometer—Heat-Sensitive Element.

## Electrical Thermometers

7. **Wheatstone Bridge Type.** The electrical circuit known as a Wheatstone Bridge is shown in Fig. 3, where R.1, 2, 3, and 4 are resistances and G a galvanometer. If the resistances are all equal, or if R.1 equals R.2, and R.3 equals R.4, the bridge is balanced, for there is no voltage difference between points A and B, and therefore no current flows through the galvanometer. If, however, the bridge is unbalanced by a variation in value of one of the resistances, A and B are no longer at the same potential and the galvanometer needle will be deflected by the resulting out-of-balance current, the amount of deflection being proportional to the change in resistance. In the thermometer version of this circuit one of the resistances is temperature sensitive (*i.e.* its value alters with changes in temperature) and is mounted in the thermometer bulb. The other three resistances, which are made from an alloy having a negligible temperature coefficient, are located inside the indicator case. By a suitable arrangement of the materials used in the bulb resistance, the bridge may be balanced at a pre-determined temperature. This, the null point, is marked on the dial face by a white spot, and is the point to which the needle should return when the current is switched off. Any departure from normal in the supply voltage will cause an error in indication which will vary from zero at the null point temperature to a maximum at the extremities of the scale. Air, oil, and coolant temperatures may be measured by thermometers of this type.

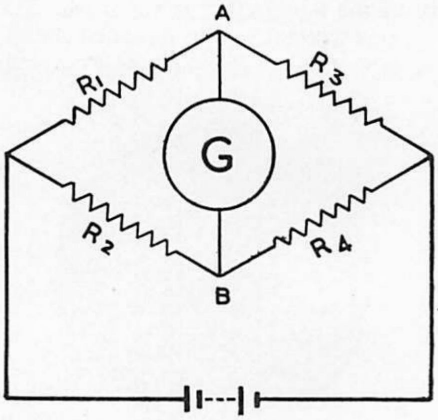




Fig. 3. Wheatstone Bridge Thermometer.

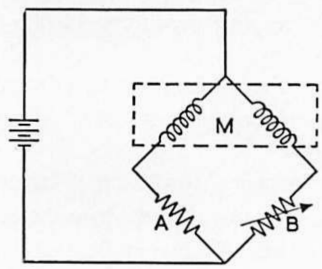



Fig. 4.
Ratiometer Thermometer—Basic Circuit.

8. **Ratiometer Type.** The basic circuit of the ratiometer thermometer is shown in Fig. 4, where A and B are resistances, the latter being temperature sensitive and mounted in the thermometer bulb, and M is a moving coil unit consisting of two coils wound on one former. These coils are wound one diagonally over the other, as can be seen in Fig. 5, and are so connected that the torques produced by them are in opposition. Inside the coil unit is a stationary soft iron core which is made slightly elliptical so that the magnetic field in which the coil unit moves is stronger at points A than at points B. Now, the coil unit will be in equilibrium when the opposing torques are equal ; consequently, the coil in the weaker part of the field must have the stronger

current flowing through it. Thus, in Fig. 5 the current in coil X passes through the fixed resistance and is constant, whereas that in coil Y passes through the bulb resistance and, in the low temperature condition shown, is the greater. As the temperature rises so also does the value of the bulb resistance and the current in Y therefore decreases, causing the coil unit to rotate clockwise until equilibrium is established. At the half-scale point the current in Y will have fallen to the same value as that in X, and at higher temperatures will be the lesser. Because the current strength in the two coils will remain in the same proportion at a given temperature, irrespective of the applied voltage, readings are unaffected by normal supply fluctuations. With the oil and radiator temperature variants the "current off" position of the needle is low off-scale, whereas with the air temperature version it is high off-scale. Dials are similar to those used with the Wheatstone Bridge circuit, except that there is no null point mark.

9. **Thermo-Couple Type.** If two lengths of dissimilar metals are joined together at both ends so as to form a circuit, and heat is applied to one of the junctions (known as the hot junction), a small E.M.F. is generated in the circuit. Such an arrangement is known as a thermo-couple, and the strength of the current generated in it depends on the temperature difference between the heated and unheated junctions, the types of metal used in the thermo-couple, and (in jet pipe temperature measurement) on the velocity of the gases. If the unheated junction (known as the cold junction) is kept at a constant temperature, a sensitive milli-voltmeter in the circuit (Fig. 6) can be graduated to indicate the temperature of the hot junction. This is the principle of the air-cooled engine cylinder head temperature gauge and of the gas turbine jet pipe temperature gauge. For convenience in practice, instead of exercising control over the cold junction temperature, a bi-metallic device is embodied within the gauge itself to compensate for cold junction

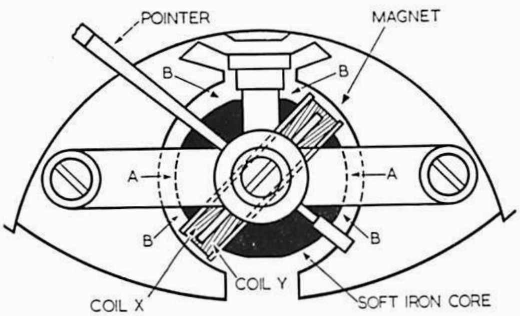
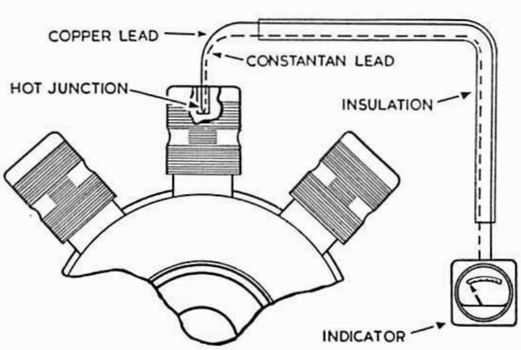




Fig. 5. Ratiometer Thermometer—Disposition of Coils and Presentation.



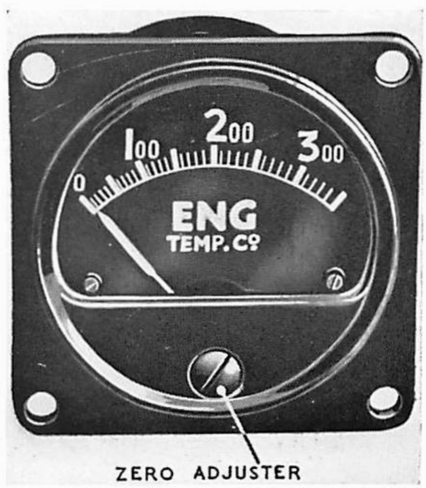




Fig. 6. Thermo-Couple Thermometer.

temperature variation. Although the gauge is really a milli-voltmeter, it is graduated in degrees Centigrade.

(*a*) *Cylinder Head Temperature Gauge*. Copper and the alloy constantan are the dissimilar metals employed in this thermometer, the hot junction being located in one of the cylinder heads (Fig. 6) and the cold junction in the indicator case. Compensation for temperature variation at the cold junction takes the form of a bi-metallic spiral which acts on the hairspring restraining the pointer. As the resistance of the milli-voltmeter moving coil varies with temperature, compensation is also provided to neutralize this effect, one form being the incorporation of a resistance with a negative temperature coefficient in series with the coil, so that an increase in resistance of the one is balanced by a corresponding decrease in the resistance of the other.

(*b*) *Jet Pipe Temperature Gauge*. One version of this instrument is similar to the cylinder head temperature gauge, but, owing to the higher temperatures involved, chromel and alumel replace the copper and constantan, and the scale extends to 800°C. The Type B (Fig. 7) is more complicated, the principal differences being that :—

(i) Four thermo-couples connected in series and spaced radially around the jet pipe are used, so that an average reading is obtained. With only one thermo-couple there is always the chance that its location may be hotter or colder than another point in the jet pipe.

(ii) Cold junction compensation is embodied in a Wheatstone Bridge circuit which, in conjunction with an external constant-voltage supply, suppresses readings below 400°C., thus making a more open scale possible.

(iii) A voltage compensation unit is incorporated to iron out fluctuations in the aircraft supply system.

The Type C has four thermo-couples arranged in parallel, the metals used being nickel-chromium and nickel-aluminium.

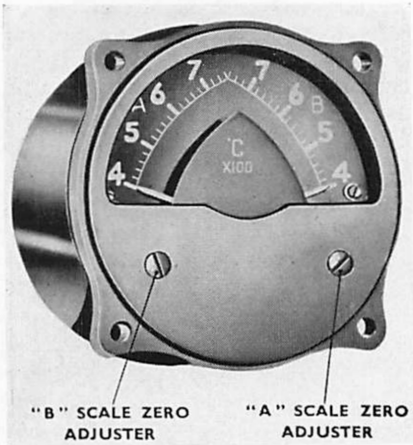



Fig. 7. Exhaust Gas Thermometer, Type B, with Twin Pointer Indication.


Instrument panel
from a
Mk4 Jet Provost
(XP558)