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MEASUREMENT OF AMBIENT AIR TEMPERATURE IN FLIGHT

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FOREWORD

In recognizing that the knowledge of ambient air temperature* on board aircraft is exceedingly important not only for meteorological purposes, but also in connection with determining icing conditions, engine performances, and corrections to the airspeed indicator, and to the pressure type altimeter, ICAO requested certain Contracting States to submit reports on the results of their investigations concerning design of aircraft thermometers, their proper exposure on aircraft, and methods of correcting the readings in order to measure ambient air temperature in flight.

As a result of this request, several Contracting States have submitted reports on the subject. The reports received up to the 1st of January 1949, have subsequently been correlated and assembled by the ICAO Secretariat for the preparation of this circular.

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* In this document the term "ambient air temperature" means the temperature of the undisturbed air surrounding an aircraft.

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SUMMARY

The ambient air temperature in flight is the temperature of the undisturbed air surrounding an aircraft. It is an important quantity used in weather and flight performance analysis. The measurement of ambient air temperature from an aircraft in flight is rather complicated, since most temperature measuring devices in the free air stream are influenced by the adiabatic compression due to the stopping or slowing down of the air. In addition, there are errors due to inherent inaccuracies in the design and construction of thermometers, instrumental time lag, radiation and conduction effects, air friction, thermometer element position on the aircraft, amount and form of moisture in the atmosphere.

However, the information obtained indicates that the ambient air temperature can be determined with sufficient accuracy for meteorological as well as for flight testing purposes, if accurate instruments and proper methods of exposure and correction are applied.

From the reports received it appears that no Contracting State as yet has attempted to standardize its equipment to measure ambient air temperature in flight and various types of thermometers are used and considered suitable for the purpose. The thermometer types in use include spirit; mercurial, bimetal and electrical thermocouples or resistance thermometers.

The methods of exposing thermometers to the air stream and of converting indicated air temperature to ambient air temperature are based in most countries on the same basic principles and appear to be applicable to any type of thermometer reported as being used at present.

In this circular the proper exposure of thermometers into the air stream and the relationship between the indicated air temperature and ambient air temperature is outlined in principle, and the design and installation of some particular aircraft thermometers is briefly described.

MEASUREMENT OF AMBIENT AIR TEMPERATURE IN FLIGHT

1.- INTRODUCTION

In order to determine the magnitude of the ambient air temperature in flight, that is, the temperature of the undisturbed air surrounding an aircraft, use is made of various types of thermometers mounted in a suitable position on the aircraft. The types of thermometers which have been reported as being used to measure the air temperature in flight are the following: spirit and mercurial thermometers with open and remote scales, electrical resistance and thermocouple thermometers and thermometers with bimetal temperature elements. Spirit and mercurial thermometers normally are simpler in construction and consequently appear to be more reliable. Mercury thermometers have their freezing point at approximately -35°C and cannot be used to measure lower temperatures. Bimetal and electrical thermometers appear to be less subjected to instrumental time lag.

Aircraft thermometers in most cases form part of an equipment unit which besides measuring temperatures is used to obtain other data such as the pressure and the humidity of the atmosphere.

In exposing aircraft thermometers into the air stream, care must be taken to ensure that the thermometer elements are not mounted in any position where air heated by the aircraft can affect it. In order to protect thermometers from direct sunlight and other radiation effects, special shields are provided or thermometers are mounted underneath the wing or fuselage. In order to expose thermometers as far as possible to the undisturbed free air stream they normally are mounted as far forward as possible towards the nose or leading edge of the aircraft and are so supported that they are in a position sufficiently remote from the skin of the aircraft to be outside the boundary layer.

In Section 3 of this circular, brief descriptions of the design and installation of some actual aircraft thermometers are given.

Irrespective of the type of thermometer and in spite of the most careful exposure of them, there exist several effects which may cause discrepancies so that the thermometer does not normally indicate closely enough the actual ambient air temperature. However, it has been found that the temperature readings obtained from thermometers which are suitably installed on present day civil transport aircraft are capable of being satisfactorily corrected to give a sufficiently good approximation of the true ambient air temperature.

In Section 2 of this circular, the relationship between ambient and indicated air temperature is outlined and the method reported by Contracting States for converting indicated airspeeds to ambient air temperatures is indicated in principle.

2.- RELATIONSHIP BETWEEN AMBIENT AIR TEMPERATURE AND INDICATED AIR TEMPERATURE

The influences which have been reported by Contracting States as having an essential effect on aircraft thermometer readings may be classified as follows:

a) Instrumental errors;
b) Effects of airspeed;
c) Position errors;
d) Time lag of instruments;
e) Effects of atmospheric conditions.

A.- Instrumental Errors

The accuracy of any quantitative measurements may be limited by the inherent inaccuracy of the measuring equipment with which the measurements are made. From the information obtained it appears, however, that aircraft thermometers of any desired accuracy and range of application can be manufactured with such precision that instrumental errors are negligible or can be eliminated by applying to the readings corrections based upon calibration tests. Such corrections, if necessary, are normally supplied for each individual thermometer in the form of correction charts.

B.- Effects of Airspeed

When air that is moving at high speed is slowed down by an obstruction, heating of the air around the obstruction occurs due to changes in air pressure and friction between the air and the surface of the obstruction. When the obstruction is the temperature element of a thermometer, the heating of the air around the surface of the temperature element affects the temperature readings and must be compensated by applying a correction to the indicated temperature to obtain the ambient air temperature.

For a thermometer in clear air moving with the true airspeed V, it is shown in Ref. 1 and in the following paragraphs that such a correction can be expressed as a function of the true airspeed V and a factor to be determined by tests for a particular thermometer arrangement.

Assuming static air flow, no external forces, negligible internal friction and adiabatic compression, the Bernoulli equation may be written as follows:

$$\frac{V_1^{\,2}}{2} + \frac{K}{K-1}\,\frac{P_1}{\rho_1} = \frac{V_2^{\,2}}{2} + \frac{K}{K-1}\,\frac{P_2}{\rho_2} \qquad (1)$$

where the index figures "1" and "2" indicate any two points in the air stream,

P = air pressure

ρ = air density

K = ratio of specific heat at constant pressure, c_{p_1}, to specific heat at constant volume, c_v.

For ideal gases the following relationships exist:

$$\frac{P}{\rho} = g\,RT \text{ and } c_p - c_v = \frac{R}{A} \qquad (2)$$

where g = gravitational acceleration, R = gas constant, T = absolute thermodynamic temperature, A= mechanical equivalent of heat.

From equations (1) and (2) the following expressions can be derived:

$$T_2 - T_1 = \Delta T = \frac{K-1}{K} \times \frac{V_1^{\,2} - V_2^{\,2}}{2gR} = \frac{1}{2gAc_p} (V_1^{\,2} - V_2^{\,2}) \quad (3)$$

From (3) it may be seen that an increase in temperature, ΔT, due to an increase in air pressure, exclusively depends on the velocity distribution and that the air density does not affect the temperature.

If thermometers were constructed in such a manner that their temperature element surfaces would lie practically within the stagnation point then the airspeed in the immediate neighbourhood of the surface of the temperature element would practically be zero and the friction between the air and the temperature element would be negligible. For such a "stagnation point thermometer" equation (3) may be written as follows:

$$\Delta T = \frac{1}{2gAc_p} (V)^2 \quad (4)$$

According to information obtained by ICAO such a "stagnation point thermometer" at present is being developed in the Netherlands and it also appears that successful use of a "stagnation point thermometer" has been made by Lockheed Aircraft Corporation (see Ref. 8).

However, the thermometers normally used in flight are not ideal stagnation point thermometers, that is, the airspeed across the surface of the thermometer element is not equal to zero and, therefore, considerable heating is caused by friction within the boundary layer of the air moving across the thermometer element.

In general, the boundary layer across such temperature elements is partly laminar and partly turbulent. In a turbulent boundary layer the velocity distribution is irregular and a theoretical approach to determine the heating due to friction appears at present to be impracticable. In the case of a static potential air flow along a flat plate with a laminar boundary layer a method is available (Ref. 3) to determine the heat increase in the gas if it is assumed that no heat is exchanged between the plate and the gas. In accordance with this method, it appears that the temperature increase in the case of laminar boundary layer can be expressed as follows:

$$\Delta T = \frac{1}{8} \beta \frac{V^2}{gAc_p} \qquad (5)$$

where β may be considered as a constant factor which depends solely on the type of gas. For air β is approximately equal to 3.6. Thus for a flat plate temperature element with laminar boundary layer the following formula may be obtained:

$$\Delta T = 0.45 \frac{V^2}{gAc_p} \qquad (6)$$

From (6) it follows that the change in temperature due to friction does not depend on the density, but does depend on the airspeed in a similar way as described for temperature increase due to impact pressure.

With $g = 9.81 \text{ m/sec}^2$; $A = 427 \frac{\text{kgm}}{\text{Cal}}$; $c_p = 0.241 \frac{\text{Cal}}{\text{kg } ^\circ\text{C}}$

the following correction formulae can be written:

a) For a stagnation point thermometer where the friction can be neglected:

$$\Delta T_1 = -0.5 \times 10^{-3} \times V^2 \quad [\Delta T \text{ in } ^\circ\text{C}, \ V \text{ in m/sec}] \qquad (7)$$

b) For a flat plate thermometer where impact pressure equals zero and the boundary layer remains laminar:

$$\Delta T_2 = 0.45 \times 10^{-3} \times V^2 \quad [\Delta T_2 \text{ in } ^\circ\text{C}, \ V \text{ in m/sec}] \qquad (8)$$

c) For a flat plate thermometer where impact pressure equals zero but the boundary layer is turbulent:

$$\Delta T_3 = \text{unknown}$$

ΔT_1 and ΔT_2 are approximately of the same magnitude, and from laboratory tests (Ref. 4) it appears that also ΔT_3 is of a similar magnitude. Since on normal thermometer heating due to impact pressure and friction in laminar and turbulent boundary layers will occur simultaneously, the total correction ΔT, for any thermometer may be written in the following form:

$$\Delta T = -\alpha V^2 \qquad (9)$$

where α is the correction factor and V is the true airspeed. Test results reported from the Netherlands and information obtained from the United States and the United Kingdom indicate that α is practically constant within the speed and altitude ranges of present day transport aircraft.

The practical determination of the correction factor, α, is done by flight tests, whereby the aircraft is flying steadily at a level of constant pressure and density at various airspeeds. If the temperature readings corrected for instrumental and position errors are then plotted against the square of the true airspeed the slope of the graph will give the value of α. The true airspeed is normally found from the indicated airspeed by converting the latter into calibrated airspeed and the calibrated airspeed into true airspeed.

In converting the indicated airspeed into true airspeed standard density is sometimes used. However, a more accurate value of the true airspeed is obtained if the standard density is corrected by taking into account the ambient air temperature.

The correction formulae for airspeed effects may differ in its practical form, examples are given below:

<u>United States</u>)
<u>United Kingdom</u>) $\Delta T = \alpha_1 \left(\frac{V}{100}\right)^2$ [ΔT in °C, V in miles/hour]

<u>Netherlands</u> $\Delta T = \alpha_2 \frac{\rho_o}{\rho} q$ [ΔT in °C, q in kg/m ^{2}]

where q is the calibrated dynamic pressure

or $\Delta T = \frac{\rho_o}{\rho} \alpha_3 \; V_{EAS}^2$ [°C, miles per hour]

The accuracy with which the correction factor can be determined appears to depend largely on the following factors:

a) The accuracy with which temperature variations can be determined on the indicator;

b) The atmospheric variations of the ambient temperature when flying at a constant pressure altitude;

c) The difference in temperature on the indicator at various speeds at a constant altitude;

i) The accuracy with which the true airspeed can be determined.

In order to determine α values, in the Netherlands (Ref. 2) a strain gauge indicator was used in connection with an electrical resistance type thermometer element. With this strain gauge indicator it was possible to read temperature variations with extreme accuracy on a dial where 20 markings corresponded to a temperature increase of 0.01°C. At constant speed the average indication could be easily determined within 100 dial markings, that is, within 0.05°C.

During tests (Ref. 2), it was found that the ambient air temperature at constant altitude varied in a few extremely unfavourable cases up to 1.0°C. However, from observations during the flight when the readings of the strain gauge indicator were read while maintaining constant airspeed during approximately 30 seconds, the temperature did not vary more than 0.3°C. In most cases the variation was very much smaller and could often even be neglected.

In a United States report (Ref. 6), it is stated that isothermal conditions are not as difficult to find as might be expected and that they most frequently occur within a high pressure system above a subsidence inversion and may be encountered ahead of a cold front about 150 metres beneath the strato-cumulus cloud deck. Variations in ambient temperatures, at constant pressure altitude, within the area of approximately 100 square miles required for a test, are considered satisfactory for the purpose of determining α if they do not exceed 0.2°C.

The differences of temperature readings made at minimum and at maximum speed amount normally from 2 to 4°C. An error of 0.2°C to 0.4°C in the reading of these temperature differences can cause an error of 10°/o in α It is therefore important to use thermometer scales which permit readings of temperature in at least one or two tenths of 1°C.

C.- Position Errors

In the speed correction formulae (9) described in the preceding paragraphs, the true airspeed, V, is included. The true airspeed is the speed of the aircraft on which the thermometer is installed relative to the undisturbed air. If this true airspeed is used in the speed correction formula care must be taken in exposing the thermometer properly into the direction of the air stream at a point of the aircraft where the velocity of the air stream is practically equal to the true airspeed of the aircraft. Such points in most cases may be found underneath the wing or fuselage as far forward as possible towards the nose or leading edge of the aircraft where no abrupt changes of curvature in the aircraft structure exist. It is normally considered appropriate to support the thermometer element so that it will be clear from the aircraft skin by not less than 10 cm (4 inches). If adequate care is taken in exposing the thermometer element, small remaining position errors can be eliminated by variations of the speed correction factor α which then may depend slightly on the position of the thermometer on the aircraft (Ref. 1).

D.- Instrumental Time Lag

In measuring temperature accurately, the time lag of the indicated instrument must be considered. When a thermometer is placed in an air stream, a period of time is required during which the thermometer gains or loses the heat energy necessary to bring it into temperature equilibrium with the air flowing past it. If the temperature of the air stream is changing, the indicated temperature of the thermometer will lag behind the air temperature, the amount of lag depending on the rate of change of the air stream temperature and the characteristics of the thermometer. The thermometer actually indicates the average temperature of the thermometer element, T_i, and if this temperature is different from that of the air surrounding the element, (T_a), a correction must be applied to the indicated temperature. In a first approximation, it may be assumed that the rate of change of the indicated temperature is proportional to the temperature difference which exists momentarily between T_i and T_a.

$$\frac{dT_i}{dt} = f\,(T_a - T_i)$$

$$\text{or} \quad \Delta T = \frac{1}{f}\,\frac{dT_i}{dt}$$

The value of f certainly will depend on the airspeed particularly at the lower speed range.

The correction factor 1/f may be determined by flight tests. To this end the temperature distribution in the atmosphere has to be determined by horizontal flights at various speeds and altitudes, in order to eliminate from these tests the time lag effects. An atmosphere must be selected in which the horizontal flights can, as closely as possible, be carried out in an isothermal layer. After determining the temperature in function of the altitude the procedure may be to fly on a magnetic heading and on its reciprocal, holding air speed constant, and ascending and descending at a uniform rate. From the relationship between time, altitude and indicated temperature it will then be possible, with the knowledge of the temperature distribution as a function of altitude, to determine the correction factor $\frac{1}{f}$.

In order to avoid the complication of correcting the temperature reading for instrumental lag, temperature readings may be made after flying in level flight for a sufficient time to permit the thermometer indication to stabilize.

The smaller the time lag of a thermometer the more accurate, of course, will be the results. For certain electrical resistance thermometers it appears that practically no time lag has to be taken into account whereas, particularly for mercury and spirit thermometers, level flights for two or more minutes may be required before taking a reading. For instruments with a high time lag it might be necessary to fly in circles at constant level in order to remain in a sufficiently isothermal area during the measurement.

E.- Effects of Atmospheric Conditions (Ref. 5)

In unsaturated air the described method of converting indicated air temperature to true ambient air temperature appears to give very accurate results. However, when flying in cloud and rain the determination of the true ambient temperature is fraught with difficulties.

According to the form of the airflow past the thermometer and according to the amount of rain or liquid cloud elements in the cloud the thermometer element in such cases will be partly or wholly wet. The amount of wetness is indeterminate in the vast majority of cases. Consequently although it is known that the correction of the thermometer reading should lie somewhere between the correction for dry bulb and that for wet bulb it is indeterminate.

In practice in British meteorological flights the procedure is to correct the thermometer reading in cloud (for thermometers with straight-through airflow) as if the bulb were wet; that is, the correction applied is r times the dry bulb speed correction factor α, where r is the ratio of the saturated-adiabatic to dry-adiabatic lapse rate.

There are further complicating factors brought about by the existence of moisture in the atmosphere.

Rain droplets falling through the atmosphere assume only slowly the temperature of their environment, which might be different from the ambient temperature at the level where the rain drops originated. These droplets upon contact with the exposed temperature element will cause the instrument to indicate the rain droplet temperature rather than the ambient air temperature. Furthermore while the airflow is heated due to the adiabatic compression at the measuring element the water drops do not undergo the same adiabatic warming. When the aircraft moves through a mixture of air and liquid water, the measuring element is exposed to contact with the adiabatically warmed air and the unwarmed water in very rapid succession. Thus, the average temperature, given by the measuring element, will be lowered too much if the heating correction described for dry air is applied in such circumstances.

It appears that insufficient knowledge is available at the present time to compensate these latter effects.

3.- DESIGN AND INSTALLATION OF AIRCRAFT THERMOMETERS

For meteorological purposes and apparently also for flight testing use is made of spirit, mercurial, bimetal, electrical thermocouple and electrical resistance thermometers. In the following text brief descriptions of some thermometer types used in various Contracting States are given.

A.- Open Scale Spirit Thermometer

The United Kingdom submitted the description of a spirit thermometer used in the psychrometer, type M.O. MK VI, by the British Meteorological Office. (See Fig. 1). The psychrometer as a whole consists of dry and wet-bulb thermometers of the alcohol in glass type, with bulbs of flat oval section. The thermometers are mounted in brass tubes which are screwed into sockets soldered on to the top plate of the bulb housing. As an anti-vibration measure the thermometers are spring mounted and they are held in position against the springs by means of caps which screw into the top of each tube.

The psychrometer is designed for making observations for air temperature and humidity from multi-engined aircraft on which it can be mounted outside the observers window a few inches clear of the skin of the aircraft. The temperature is measured by the dry bulb thermometer of the psychrometer. This thermometer shows temperatures within a range from - 60 to + 80°F and is practically free from instrumental errors. Detailed information on this instrument can be found in the "Meteorological Air Observer Handbook" published by H.M. Stationery Office, London.

B.- Open Scale Mercurial Thermometers

Information from the United States indicates that mercurial thermometers are used in the Psychrometer Equipment ML-313/AM (see Fig. 2). This instrument was designed for use as standard humidity measuring equipment with which aerographs can be flight calibrated. However, this instrument is equally suitable for use when measurements of temperature and humidity of high precision are required.

The Psychrometer ML-313/AM includes two interchangeable psychrometer supports. One support holds two thermometers which range from - 35°C to + 15°C, the other support holds two thermometers which range from - 0.2°C to + 50°C. The range of temperatures being measured determines which psychrometer support is to be used.

A psychrometer support holds two right-angle mercurial thermometers located inside the aircraft cabin and in such a position that the mercury bulbs extend into the air stream passing through a ventilator and with the thermometer scales in such position that they can be read inside the cabin of the aeroplane. A cylindrical shield is provided to be slipped on to the psychrometer when not in use to protect the mercury bulbs from breakage. The ventilator serves to hold the psychrometer in the proper working conditions and to reduce the velocity of the air stream striking the thermometer bulbs from true airspeed of the aircraft to a value, at which the usual psychrometric methods are applicable. The ventilator consists of a highly polished streamlined radiation shield containing a cone-shaped passageway for the air. The air entering the small diameter end of the conical passageway is slowed down as the cross sectional area of the passageway increases. At the same time, the air pressure increases in accordance with the theory of Bernoulli. The ventilator should be located on the outside of the fuselage on the right side as far forward as possible, so that the air entering the ventilator will not be affected by the propellers or motors and so that the minimum dust will enter the ventilator during takeoff and ground handling. The axis of the ventilator must be parallel with the air stream. It is also important for accurate observations that the thermometers be well lighted, preferably from the rear, and as conveniently accessible to the observer in the plane as possible. This instrument has a comparatively high lag and 2 minutes flight after entering an isothermal layer might be required to stabilize the readings.

C.- Mercurial Distance Thermometers

The Netherlands report that use is made of mercurial distance thermometers of the NZI Type (Negretti and Zambra). This mercurial thermometer (Fig. 3) consists of a mercury bulb which is connected to a remote indicator by a long flexible capillary tube. The indicator is mounted at a suitable place in the crew compartment while the temperature element is mounted outside of the aircraft at a place where the air stream has a speed approximately equal to the true airspeed. A shield around the temperature element protects the instrument against direct sunlight. The instrument has a comparatively high time lag.

D.- Bimetal Thermometer

In the United States an Aerograph Equipment (A type AN/AMQ-2) has been designed for installation on long range high speed aircraft and is used to obtain accurate records of pressure, temperature and humidity in the atmosphere together with the airspeed of the aircraft. The data thus

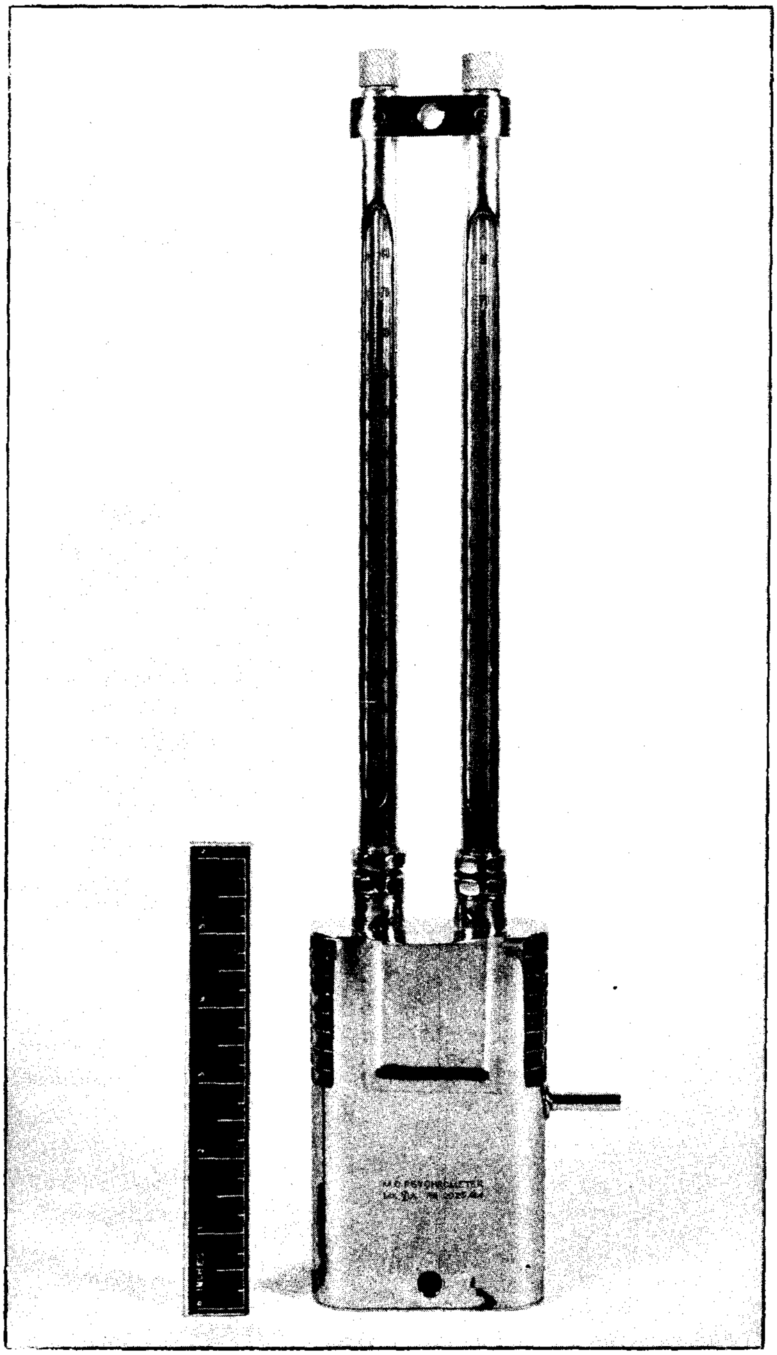

Fig. 1

M.O. Aircraft Psychrometer Equipment Mark VI.
Psychromètre modèle M.O. Mark VI.
Psicrómetro de aeronave, modelo M.O. Mark VI.

Fig. 2a

Psychrometer equipment ML-313/AM. Installation of the temperature element and its streamlined ventilator and shield on the side of the fuselage of the aircraft.

Psychromètre modèle ML-313/AM. Installation sur la paroi du fuselage de l'élément thermométrique avec son ventilateur et son capotage carénés.

Psichrómetro modelo ML-313/AM. Elemento termométrico, con su ventilador y envoltura carenada, montado en el costado del fuselaje.

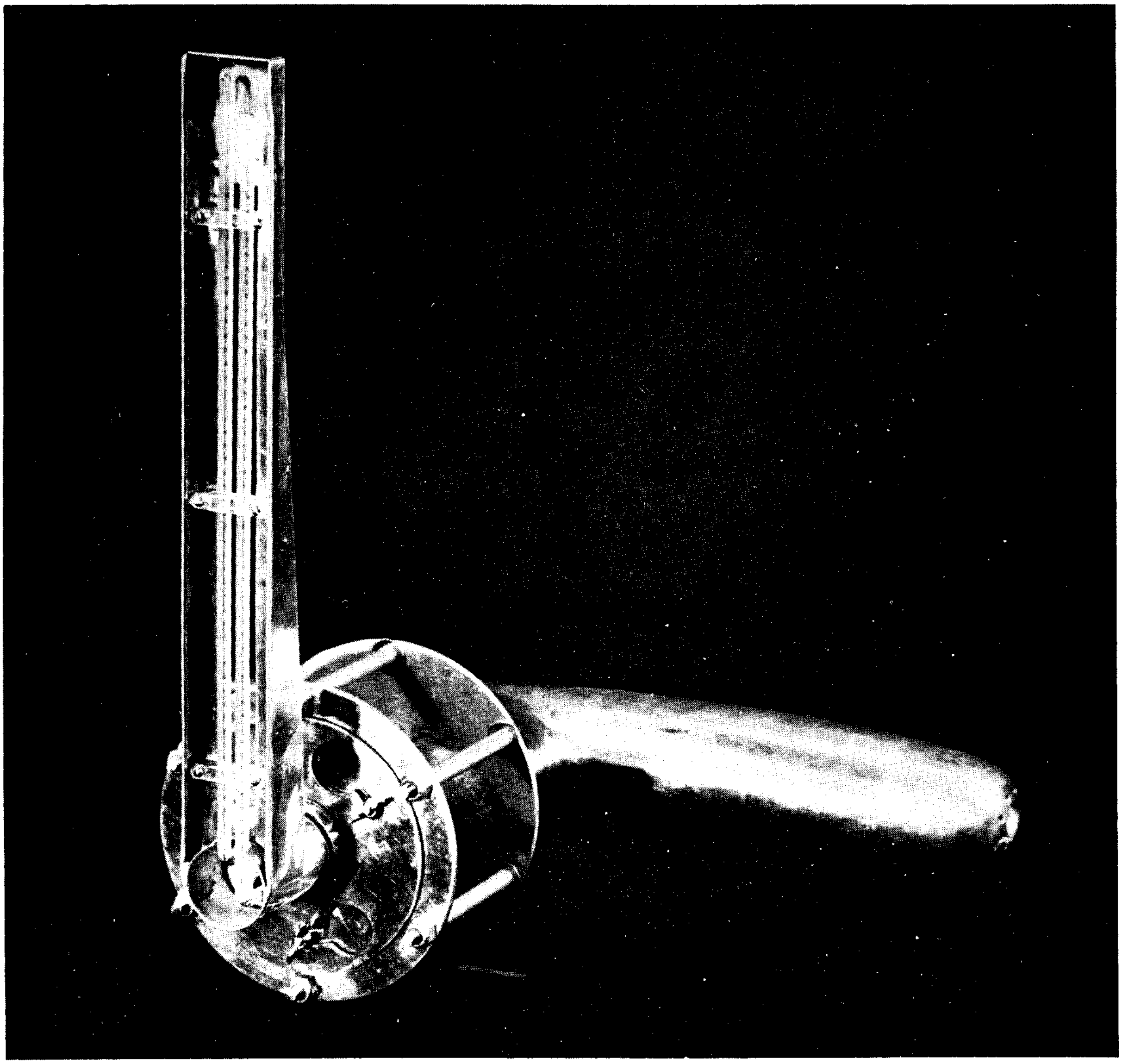

Fig. 2b

Thermometre scale (Psychrometer equipment ML-313/AM) attached to the ventilator-shield.

Psychromètre modèle ML-313/AM. Ensemble.

Psicrómetro modelo ML-313/AM. Conjunto.

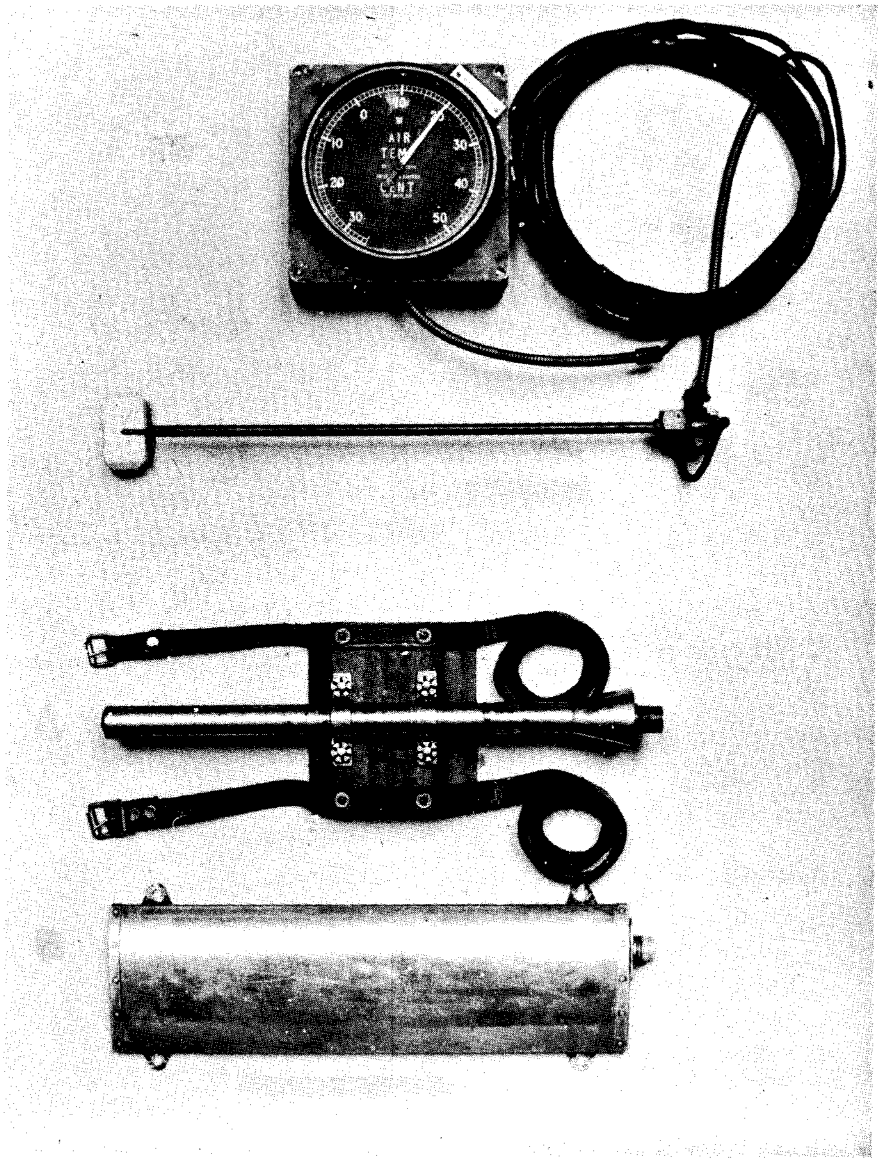

Fig. 3

NZI Mercurial distance thermometer.
Top: Complete thermometer. Below: Shield types.

Téléthermomètre à mercure NZI.
En haut: Thermomètre complet. En bas: Capotages parasoleil.

Telemometro de mercurio NZI.
Arriba: Termometro completo. Abajo: Envolturas protectoras contra el sol.

obtained are evaluated, corrected and used for weather analysis. This aerograph equipment shows temperatures within the range from - 70°C to + 50°C. The aerograph may be used to record data for both horizontal and vertical soundings. In respect of temperature the accuracy of the aerograph equipment allows for a tolerance of ± 1°C relative to the standard calibration set for which the previously described psychrometer equipment ML-313/AM might be used.

The temperature transmitter is actuated by a bimetal thermometer element. This element consists of a compound spiral of metal (see Fig. 4) formed by welding together two strips of different metals, and rolling the resulting compound. When it is exposed to temperature changes, the bimetal coils or uncoils because of the different rates of expansion and contraction of the two metals. To protect the self-synchronous transmitter from corrosion, the bimetal is enclosed in double walled finned tube (see Fig. 4). The fins on the tube increase the surface exposed to the atmosphere and cause faster dissipation of the heat. The entire unit is fluid-filled to assist in the rapid transfer of heat to or from the bimetal and is closed by a disk on which the electrical terminals are mounted. A small volume of air is left to provide for expansion of the liquid. Because the element is attached to the rotor shaft of the self-synchronous transmitter, the movement of the spiral bimetal, due to temperature variation, causes a change in the position of the rotor relative to its stator. Thus movement is communicated to the recorder chart through a remote indicating system. The temperature element is factory set, and no adjustments should be necessary in the field.

The temperature element together with a hair hygrometer element with their respective self-synchronous transmitting units are housed in an aluminum tube provided with a radiation shield projecting at the nose end and a tapered tail piece (Fig. 4).

On multi-engined aircraft the temperature humidity transmitter is mounted as far forward as possible of the fuselage. In general, the location of the detecting unit on the aircraft is governed by similar considerations as for thermometers already described.

E.- Electrical Resistance Thermometers

The United Kingdom and the Netherlands report successful use of electrical resistance thermometers. In the United Kingdom such thermometers are used in the psychrometer equipment M.O. M.K.I (see Fig. 5). This psychrometer consists of three parts: the balanced bridge indicator, a dry bulb, and a wet-bulb thermometer element. The indicator comprises a Wheatstone's bridge of which the variable arm consists of a circular slide wire. The balance of the bridge is indicated on a small-reading galvanometer and the position of the slider at the balance indicates the temperature. A switch is provided so that either the dry-bulb element or the wet-bulb element may be connected to the bridge. Each element consists of a knife shaped platinum resistance thermometer, the wet-bulb element having a wick and container for distilled water. The wire of each element is wound on a flat mica former which is stiffened. The resistance wire is covered with thin mica strips and then placed in a brass sheath. Each element is carried in on aluminium shield which is mounted near the leading edge on the underside of the wing (single-engined aircraft) or on the underside of the nose of the fuselage (multi-engined aircraft). The two housings are side by side when viewed from in front, and in line when viewed from one side of the aircraft.

In the Netherlands, the National Aeronautical Laboratory (NLL) in Amsterdam developed a similar electrical thermometer for test flying. There the temperature indicator is normally a cross-coil indicator. However, for high precision readings it has been found suitable to use an electrical strain-gauge indicator which easily allows temperature readings within an accuracy of 0.05°C as compared with an accuracy of 0.3°C with the cross-coil indicator. A detailed description of this electrical thermometer is contained in NLL Report No. V.1370.

4.- LIST OF SYMBOLS

A	Mechanical equivalent of heat
c_p	Specific heat at constant pressure
c_v	Specific heat at constant volume
1/f	Instrumental time lag correction factor
g	Gravitational acceleration
K	Ratio of specific heats $[c_p/c_v]$
p	Air pressure

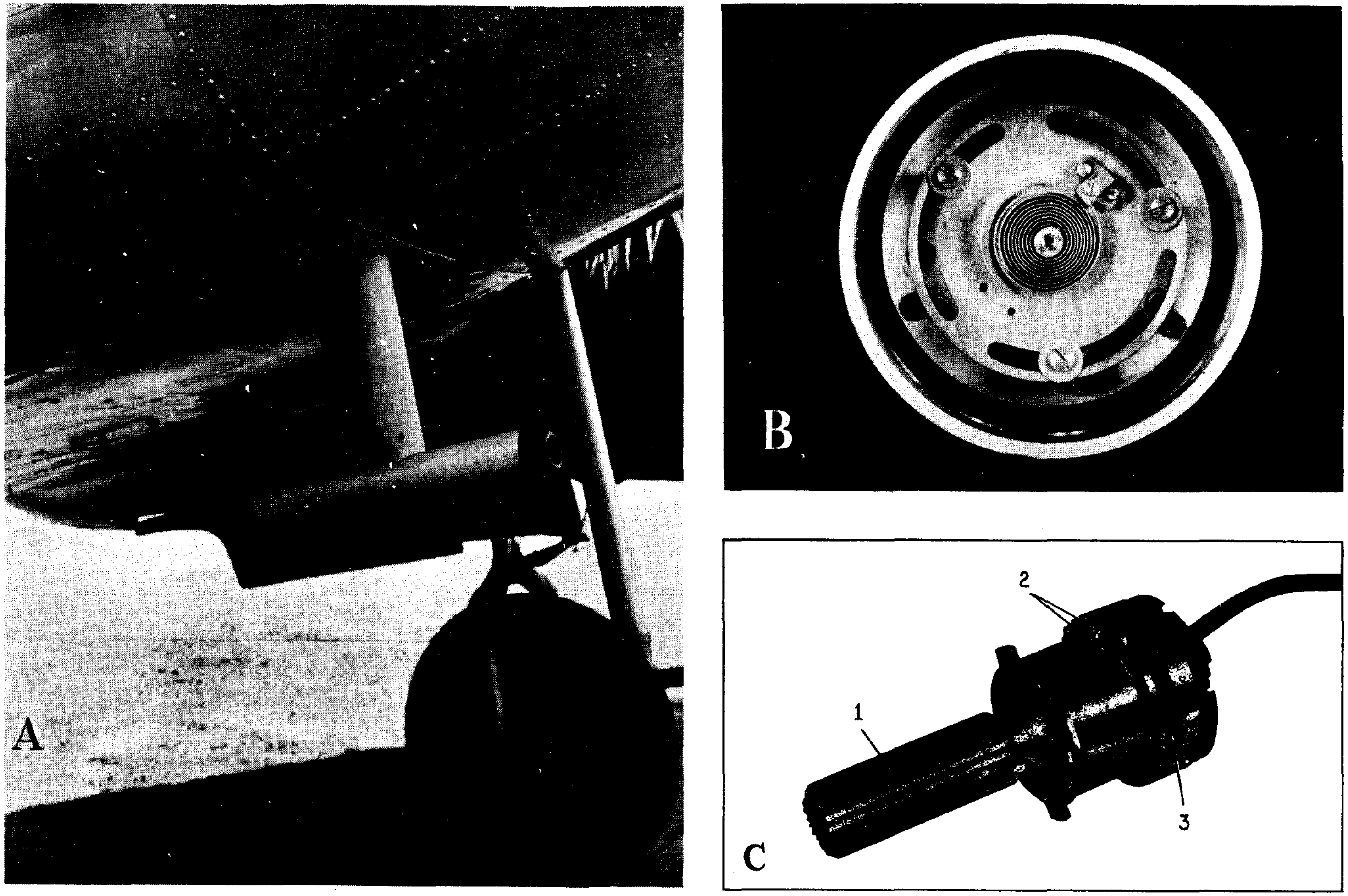

Fig. 4

Bimetal type thermometer of aerograph equipment Type AN/AMQ-2.

A) Installation of temperature-humidity;

B) Bimetal spiral thermometer element;
C) Temperature transmitter.

Thermomètre à lame bimétallique de l'aérographe modèle AN/AMQ-2.

A) Installation des éléments thermométrique et hygrométrique;
B) Spirale bimétallique du thermomètre;
C) Elément thermométrique.

Termómetro de lámina bimetal de Aerograph Equipment tipo AN/AMQ-2.

A) Instalación del transmisor temperatura - humedad;
B) Elemento termométrico de espiral bimetal
C) Transmisor de temperatura.

1) Finned tube - tube à ailettes - tubo de aletas
2) Tightening screws - vis d'assemblage - tornillos de estanqueidad
3) Expansion ring - joint de dilatation - anillo de dilatación

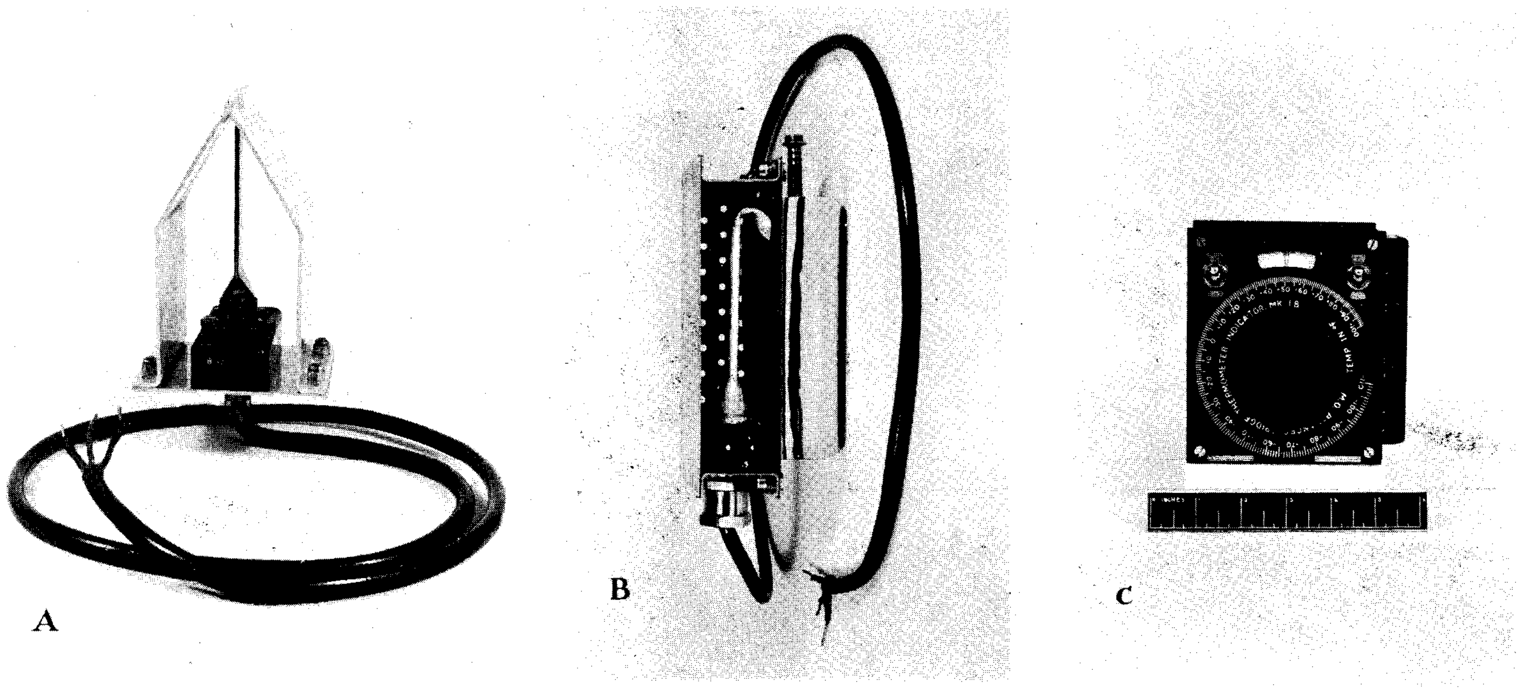

Fig 5

Electrical resistance thermometer Type M.O. Mark I.

A) Dry bulb element.
B) Wet bulb element.
C) Balanced bridge thermometer indicator.

Thermomètre à résistance électrique modèle M.O. Mark I.

A) Elément sec.
B) Elément humide.
C) Indicateur thermométrique à pont équilibré.

Termometro electrico de resistencia, tipo M.O. Mark I.

A) Bulbo seco.
B) Bulbo humedo.
C) Indicador de temperatura de puente equilibrado.

q	Dynamic pressure
R	Gas constant
r	Humidity correction factor
T	Absolute ambient temperature
ΔT	Temperature correction
T_a	Air temperature outside thermometer element
T_i	Temperature of thermometer element
t	Time
V	True airspeed
V_{EAS}	Equivalent airspeed $= V (\rho/\rho_o)^{\frac{1}{2}}$
α	Speed correction factor
β	Constant factor
ρ	Air density

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Figure 1	-	National Aeronautical Research Institute, Amsterdam.
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Figure 5	-	Meteorological Office, Air Ministry, London, England.

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