C.P. No. 781

C.P. No. 781

MINISTRY OF AVIATION

AERONAUTICAL RESEARCH COUNCIL

CURRENT PAPERS

Flight and Tunnel Tests to Develop a Thermal Detector for Determining the Boundary Layer State

by

Ann Cronin and O. P. Nicholas, B.Sc.(Eng.)

LONDON: HER MAJESTY'S STATIONERY OFFICE

1965

SIX SHILLINGS NET

U.D.C. No. 533.6.082.7 : 532.526

C.P. No. 781

February 1964

FLIGHT AND TUNNEL TESTS TO DEVELOP A THERMAL DETECTOR FOR DETERMINING THE BOUNDARY LAYER STATE

by

Ann Cronin
and
O.P. Nicholas, B.Sc.(Eng.)

SUMMARY

An investigation has been made into the suitability of a thermal detector for determining the boundary layer state on an aircraft, based on the principle of more rapid heat transfer across a turbulent, compared with a laminar, boundary layer. Following successful laboratory and wind tunnel tests, a few subsonic flight tests with the detectors mounted in a flat plate showed that they could be used satisfactorily to determine boundary layer state. This detector can be used to a working temperature of 80°C and hence could be used to give adequate signal changes up to a Mach number of 1·5 above the tropopause. Further laboratory tests on another detector of similar design using higher temperature components suggest that it could be used up to a Mach number of 1·9 above the tropopause.

Replaces R.A.E. Tech Note No. Aero 2953 - A.R.C. 26010

CONTENTS

ILLUSTRATIONS

1 INTRODUCTION

It is important to know the state of the boundary layer in flight as it affects skin friction, heat transfer and flow separations. A convenient method of indication is required which may be used in flight on high performance aircraft.

The position of transition is commonly determined in wind tunnel tests by spraying the surface with a subliming chemical. This method has been used in full scale flight tests[1,2] and has the advantage of giving a complete picture over a given area. It can reveal the presence of "wedges" of turbulence in an otherwise laminar region and Ref.3 contains an example of the serious thermal effects which such "wedges" can produce in high speed flight. However the sublimation technique has the disadvantage that it can only give an average indication of the boundary layer state during the flight, as it is only normally possible to observe the results after the flight. Thus the flight condition to be investigated must occupy the major part of the flight and this is frequently not possible with high performance aircraft. Furthermore, previous experience[2] has shown that several flights may be necessary to determine a suitable combination of thickness of chemical layer and time required to give an indication of transition.

Because of these difficulties other methods of determining the boundary layer state have been considered. The most promising method is thought to be one based on the difference in heat transfer across laminar and turbulent boundary layers. Being relatively insensitive to flow direction, the method is ideally suited to the investigation of the flow on a swept back wing, which may not be along the free stream direction. This paper describes the development and assessment, in wind tunnel and flight tests, of a detector similar to an American type[1,4] which can instantaneously determine the state of the boundary layer at discrete points. The detectors have been developed for use on the Bristol 221 slender wing research aircraft. For convenience they will be installed at pressure plotting orifice positions, and will thus be flush with the wing surface.

2 PRINCIPLE OF THERMAL TRANSITION DETECTORS

The heat transfer factor, h, for a turbulent boundary layer is approximately ten times greater than that for a laminar boundary layer, other conditions being identical. It is also a function of Mach number, altitude and Reynolds number.

If an electrically heated element is mounted flush with the surface of an aircraft but thermally insulated from the local structure, its temperature in flight will be a measure of the local heat transfer across the boundary layer. Fig.1(a) shows the heat balance, under stabilised conditions, between the heat dissipated in the element and the heat transferred to the boundary layer and structure. If W is the heat dissipated by the element per unit area,

$$W = q_R + q_E + q_{INT} \tag{1}$$

where $q_R = \sigma\varepsilon\left(\frac{T_W}{1000}\right)^4$ - radiated heat per unit area

$q_E = (T_W - T_r)h$ - heat conducted to the boundary layer per unit area, T_r being the local recovery temperature

$q_{INT} = (T_W - T_s)\frac{k}{d}$ - heat conducted to the structure per unit area.

For a point on the aircraft under given flight conditions, a change in boundary layer state will affect T_r and T_s slightly, and h very considerably.

Thus
$$\frac{\partial T_r}{\partial h} \doteqdot 0 , \quad \frac{\partial T_s}{\partial h} \doteqdot 0 .$$

For a typical element, q_R is negligible. q_{INT} is larger than q_E since k/d is greater than h, but a change in h, between laminar and turbulent flow, is still sufficient to produce a significant change in T_W. The sensitivity of the element to changes in h may be defined as $\frac{\partial T_W}{\partial h}$. Differentiating equation (1), assuming that the change in the electrical power, W, dissipated is relatively small,

$$\frac{\partial T_W}{\partial h} \doteqdot - \frac{(T_W - T_r)}{\left(h + \frac{k}{d}\right)} .$$

Thus for given element and flight conditions, the sensitivity depends on $(T_W - T_r)$. The upper limit to T_W is fixed by the temperature limits of the materials used; therefore, for a given sensitivity, the maximum value of T_r, and hence maximum Mach number, is fixed. The value of the heat input, W, required at the maximum value of T_r is determined by equation (1), and in practice W is held approximately constant at this value throughout the speed range up to this Mach number.

When a chordwise row of nominally identical elements is used, the temperature of one may be taken as a reference and the temperatures of the others compared with it. In this way the effects of ambient temperature, Mach number and altitude on the heat transfer can be suppressed. This leaves only a relatively small effect of distance from the leading edge, through the dependence of heat transfer factor on Reynolds number, and the major effect of the boundary layer state, laminar or turbulent. The reference detector would be made the rearmost of the row and have artificial roughness ahead of it to guarantee turbulent flow over it under all flight conditions Fig.1(b) shows the variation in temperature difference with distance along such a row of elements, if the flow altered from laminar to turbulent midwa along the row. The heated elements mounted on an insulated backing are defined in this Note as transition detectors.

3 LABORATORY TESTS

These tests were made with detectors attached to a 0·375 inch thick aluminium alloy plate to simulate the heat conduction effects of the surrounding aircraft skin. The aim was to produce a detector for which the heat transfer to the air was large compared with that to the surrounding structure, with a high operating temperature and a low response time. A co venient measure of the first aim is the temperature rise, in still air, per unit power dissipation, per unit area of the detector. For comparative pur poses this has been defined as the efficiency K, in °C rise/Watt/sq in.; the higher the value of K the greater the efficiency of the detector.

The objects of the laboratory tests were to find for each type of detector:

(1) The value of K.

(2) The maximum temperature to which the detector could be heated without damage.

(3) Whether there were significant differences in characteristics between nominally identical detectors.

A few brief tests were made using a detector of the type shown in Fig It consisted of a hollow screwed plug of resin bonded asbestos with a therm istor and heating coil fixed in it with ceramic cement, and had the advanta of being small. This detector was heated by passing a current through the heating coil and its temperature was measured by the thermistor. It could used to a temperature of 180°C. However, the highest value of K which coul be achieved was 0·14 which was considered to be much too low. In spite of using various other thermal insulators, the values of K measured continued be unsatisfactorily low and this type of detector is not considered suitabl

Refs.1 and 4 describe a detector which used a simple resistance-thermometer gauge which acted as the heating element, heated surface and temperature measuring device, all in one. The gauge was mounted on a piece of fabric-base bakelite sheet to insulate it thermally from the aircraft sk The thickness of this insulation was 0·013 inch and the total thickness of the detector was 0·018 inch. These detectors were glued to the skin of the aircraft wing and the surrounding area of the wing was built up to the same thickness with fibre glass cloth. Laboratory tests showed these detectors had a K of approximately 2·0 and a maximum operating temperature of 200°C; they were used successfully in flight up to $M = 2{\cdot}0$. It was decided to develop a type, similar to this American one, but suitably modified so that it could be mounted flush with the aircraft skin. As this would involve cutting a hole in the wing skin, the area of the detectors had to be reduce to a minimum, but the thickness could be increased above that of the American version.

The resistance elements used have a thickness of approximately 0·01 inch and consist of nickel wire elements bonded between two layers of bakelite. The working area of the elements is 0·13 sq inches and their resistance at 20°C is nominally 100 ohms. Four resistance elements were used in the initial laboratory tests. Each was attached, Fig.3, with araldite to a piece of synthetic resin bonded fabric, 0·1 inches thick to act as a detector, and mounted on an aluminium alloy plate. Synthetic resin bonded fabric and araldite were used in these tests for convenience of manufacture, although this limited the operating temperature of the element below that which could be achieved using other materials.

The resistances of several unmounted elements were measured at various temperatures in an oven. Fig.4 shows a typical calibration for one of the elements compared with the standard relation obtained assuming the characteristics of pure nickel and the resistance of the gauge at room temperature. The agreement is very good, and hereafter the standard relation has been assumed whenever it has been necessary to derive the temperature of a detector from its resistance.

K, the temperature rise in still air per unit power dissipation, per unit area, of the detectors was determined by applying various voltages across them, measuring the current and hence calculating the resistance. The temperatures of each detector were determined from the standard resistance-temperature relation. Fig.5 shows, for one detector, the rise in temperature above ambient versus the power dissipated. The relation is linear up to a temperature rise of 60°C, but above this temperature it becomes non-linear. Repeat calibrations showed no change, indicating that the non-linearity was not due to overheating producing a permanent change in the gauge characteristics. The other three detectors tested gave similar results. K is constant up to a temperature rise of 60°C, and is between 5·7 and 6·6. In the analysis of flight results the detectors are assumed identical, (see Section 2), but the scatter of ±7% in a small batch was considered small enough to be acceptable.

The first signs of overheating occurred at 95°C, when a slight discolouration of the detector became apparent. This was due to the araldite scorching, blistering and lifting the resistance elements from the surface of the synthetic resin bonded fabric. The maximum safe temperature to which the detectors could be used was set at 80°C. Although this temperature was relatively low, it was adequate for the low recovery temperatures that would be encountered in the initial wind tunnel and flight tests. The same construction was therefore retained for these tests because of its ease of manufacture. It was decided to limit the potential drop across the gauges to a maximum of 12 volts, corresponding to a temperature rise of approximately 55°C above ambient in still air.

To determine the heat transferred to the air, compared with that lost to the alloy plate, an additional element, Fig.6, was mounted over a hole cut in a piece of cardboard. The size of the cardboard was similar to that of the alloy plate used in the previous tests, to give a similar convection pattern. Heat was transferred to the air from both faces of this resistance element, while heat was transferred directly to the air from only one face of the detectors already described. Fig.7 shows the temperature rise above ambient versus power dissipated; K is 25·7, which is approximately four times that for an alloy-mounted detector. Thus, since the alloy-mounted detectors have only one side of the element exposed to the air, considerably more than three quarters of their heat input is lost in conduction to the surrounding alloy plate.

This test shows that the detectors are relatively inefficient, but their value of K approximately 6·0 still compares favourably with that of 2·0 obtained for the detectors in Refs.1 and 4. The American detectors could, however, be used at higher temperatures, because of the different materials used in their construction. The increase in K in the present tests can be attributed to the considerable increase in thickness in thermal insulation over the American type.

4 WIND TUNNEL TESTS

Following encouraging laboratory tests, transition detectors of the same general construction were tested in a wind tunnel.

4.1 Description of detectors

The following methods for the construction and installation of the transition detectors were adopted. A resistance element was cemented with araldite into a milled recess in a piece of synthetic resin bonded fabric as shown in Fig.8. When the araldite had hardened the detector surface was rubbed down until it was completely flat and the element surface was free from surplus araldite.

As it is not easy to guarantee laminar flow over normal aircraft surfaces during flight, it was proposed eventually to flight test the detectors installed in a flat plate outside an aircraft boundary layer. The detectors were therefore mounted in a flat aluminium alloy plate, Fig.9, to simulate the surrounding aircraft structure that would be present in their final application. To install a detector, a cavity of the same shape but slightly larger, was milled in the surface of the plate. Holes were drilled through the bottom of the cavity. It was filled with very viscous araldite and the detector was pressed down into the cavity with its wire leads taken through one hole. The surplus araldite was forced through the holes, leaving the top of the detector flush with the surface. Elements thus mounted had only slightly greater heat loss to the surrounding structure than those in the original laboratory tests. K for the mounted transition detectors was approximately 5·8 compared with approximately 6·0 in the original laboratory version.

The plate was made of 0·375 inch aluminium alloy and was 12 inches long and 10 inches wide with a 27° bevelled leading edge. This was roughly twice the size of that planned for the subsequent flight tests, so that the Reynolds numbers for flight and tunnel tests should be comparable. Two detectors, referred to as Nos.1 and 2, were mounted in the plate as shown in Fig.9. The flow conditions over the part of the plate in which No.1 detector was mounted could be varied by a probe, mounted in front of the plate. The probe was designed to leave the flow undisturbed when in the retracted position and to generate a wedge of turbulent flow when it was extended. No.2 detector was used as a reference. The flow over this detector was made permanently turbulent by fixing a piece of plasticine in front of it. The positions of the detectors represented those it was planned to use for the flight tests. The detectors were deliberately chosen so that they were not perfectly matched, i.e. at room temperature the resistances of the gauges were different. The underside of the plate was backed with 0·125 inch thick synthetic resin bonded fabric to reduce unrepresentative heat losses to the flow over this surface. The plate, whose top surface was highly polished, was supported between two side panels which extended to a height of 1·25 inches above it.

4.2 Tests made

It was first established in the tunnel, using the oil flow technique of flow visualization, that laminar flow existed over the entire upper surface of the plate at an incidence of -8°, up to at least 300 ft/sec, and that turbulent flow was created over No.2 detector by the plasticine. Limited tests, at 200 ft/sec, in which the probe height was varied showed that the resistance of No.1 detector was independent of probe height when the probe extended more than 0·19 inches above the leading edge of the plate.

Nos.1 and 2 detectors were connected into a bridge circuit, Fig.10, firstly to measure their resistances independently so that the temperatures of the detectors could be determined, and secondly to compare their resistances in terms of an out of balance current. The tunnel tests were made at speeds ranging from 100 ft/sec to 300 ft/sec. Fig.11 shows the variation with tunnel speed of the temperature of the reference detector, No.2, and that of No.1 detector under laminar and turbulent conditions. The temperature of No.1 detector is reduced with increasing tunnel speed and is consistently lower for turbulent flow due to the higher heat transfer. The temperature of No.2 reference detector, which was in permanently turbulent flow, also decreases with increase of tunnel speed, but the results show some peculiarity at 150 ft/sec. However, the results of Fig.12, which shows the variation with tunnel speed of the out of balance current between Nos.1 and 2 detectors for laminar and turbulent flow over No.1 detector, suggest that the peculiarity noted on Fig.11 is genuine.

5 FLIGHT TESTS

A short series of flight tests was undertaken with the detectors mounted in a flat plate essentially the same as tested in the tunnel. The only significant differences were that the plate area was reduced to approximately a quarter to limit the aerodynamic loads and thus ease the mounting problems, turbulent flow over the reference detector was tripped by 0·01 inch carborundum granules, and an extra detector, No.3 Fig.13, was added and was always immersed in laminar flow. Fig.14 shows the plate mounted on a detachable panel which was fitted to the underside of the fuselage of a Venom N.F.3 aircraft 6 feet from the nose. The plate was mounted 4 inches away from the fuselage surface to ensure it was well clear of the fuselage boundary layer, which was estimated to be approximately 1 inch thick at test conditions, and was set at a negative incidence of 8°. A magnetically operated probe, of 0·064 inches diameter, could be extended 0·125 inches above the top of the plate to create turbulent flow over No.1 detector. The local flow in this position is expected to be parallel to the skin, and effects of aircraft incidence should be small. No flow separations are expected ahead of the plate position.

The detectors were connected into a bridge circuit as shown in Fig.15. This enabled the resistance of either No.1 or No.3 detector to be compared directly with that of the reference detector, in terms of the out-of-balance current either on a direct reading galvanometer in the cockpit or recorded on a Hussenot A.22 recorder. The voltage across each detector was limited to approximately 12 volts to avoid over heating effects.

The flight tests covered a range of indicated speeds from 150 to 275 knots at altitudes from 5,000 to 30,000 feet. The Reynolds number at Nos.1 and 3 detectors, based on the distance from the leading edge, varied between $0{\cdot}16 \times 10^6$ and $0{\cdot}37 \times 10^6$; at the reference detector the Reynolds numbers were twice as great. Before any readings were taken an observer in the aircraft checked with the direct reading galvanometer that the conditions in the bridge were stable. Records were taken under stabilized flight conditions, with No.3 detector in circuit, and with No.1 detector in circuit, with the probe both retracted and extended.

Fig.16 shows the out-of-balance galvanometer current for Nos.1 and 3 detectors compared with No.2 detector, for different boundary layer conditions, as a function of aircraft indicated speed over the range of altitudes covered by the tests. The galvanometer current for a laminar boundary layer is independent of flight condition for both Nos.1 and 3 detectors. With the probe extended the galvanometer current for No.1 detector is independent of altitude but dependent on speed. The results suggest that at the higher speeds the probe is generating turbulence satisfactorily over No.1 detector, but at lower speeds the flow behind the probe may not be wholly turbulent. To check this effect, a flight was made with the probe retracted and a strip of 0·01 inch carborundum granulated roughness placed in front of No.1 detector. The galvanometer currents were recorded over the same speed range at 5,000 feet and 20,000 feet and the results are also shown in Fig.16. In this case, with turbulent flow fully developed over No.1 detector, the curre[illegible] is independent of flight conditions, thus indicating the probe does not generate fully turbulent flow at the lower speeds.

The transition detectors behaved satisfactorily over the range of conditions in which they were tested. With a power dissipation to give a detec tor temperature 50°C above ambient in still air, very adequate signal change were obtained due to transition in flight. To prevent over-heating, the maximum safe working temperature of the detectors is 80°C. This limits thei use to $M = 1{\cdot}5$ above the tropopause, corresponding to a recovery temperature of 30°C. In fact, an additional safety factor exists in flight since the temperature rise is then lower than the 50°C in still air, due to the coolin effect of the airstream.

The response time of No.1 detector to the change in conditions produce by the probe was determined from records taken while its resistance was stabilizing after the probe had been either extended or retracted. From the limited number of records available the time constant is between 2 and 4 seconds, and there is no evidence of systematic variation over the range of flight test conditions.

6 FINAL LABORATORY TESTS

Since the type of detector already described was not suitable for use above $M = 1{\cdot}5$, further laboratory tests were conducted to assess the possibility of using different materials for a detector suitable for use at higher recovery temperatures. Resistance elements were attached with bakelite cement to asbestos bonded material; individually the components of this system may be used up to 170°C. The same arrangement was adopted as for the original detector except that the backing material thickness was increased from 0·1 inches to 0·16 inches to represent the thickness to be used on the Bristol 221 aircraft. Two detectors were made using respectively asbestos-fabric and asbestos-paper base material. Tests similar to those for the original detector showed that discolouration, due to overheating, occurred at 145°C. Whilst this temperature is lower than that for the individual components, it is almost certain that 170°C is being exceeded in parts of the detector due to local overheating.

For the asbestos-fabric backed detector, Fig.17 shows the temperature rise above ambient versus power dissipated in the element; it is almost linear to a temperature rise of 120°C and gives a value of K, the efficiency of the detector in °C/Watt/sq in. of approximately 5·0. Fig.18 shows a similar result for the asbestos-paper backed detector, K being 4·0. The detectors using asbestos material are thus slightly less efficient, in terms of K, than those using synthetic resin bonded fabric even though the thickness of insulation has been increased from 0·1 inches to 0·16 inches. This reflects the higher thermal conductivity of the asbestos base materials. However, to compensate, the asbestos backed detectors may be used safely up to surface temperatures of 130°C which, allowing for a rise of 50°C above the recovery temperature, means they may be used at recovery temperatures of 80°C corresponding to approximately $M = 1{\cdot}9$ above the tropopause. It is desirable to test these modified detectors in flight at supersonic speeds so that these figures may be verified.

7 CONCLUSIONS

A thermal detector has been developed for the determination of boundary layer conditions in flight. The detector uses a nickel resistance element attached to a thermally insulating backing, and may be mounted flush with the aircraft skin. The detectors have been tested satisfactorily, installed in flat plates, in a low speed wind tunnel and in limited subsonic flight at Reynolds numbers between $0{\cdot}16 \times 10^6$ and $0{\cdot}37 \times 10^6$. The detectors have a time constant of approximately 3 seconds and may be used to a maximum safe working temperature of 80°C, thus enabling them to be used up to $M = 1{\cdot}5$ above the tropopause.

By suitably changing some of the materials used in the construction of the detector, laboratory tests have shown that it may be used safely up to a working temperature of 130°C with a small loss of efficiency. The modified detector should be satisfactory up to a recovery temperature of 80°C, or a Mach number of 1·9 above the tropopause. The modified detector has not yet been flight tested, but it is planned to test it at supersonic speeds. Provision is being made in the Bristol 221 research aircraft for the flush mounting, on the upper and lower wing surfaces, of some of these detectors.

SYMBOLS

d	thickness of backing material
h	local heat transfer factor
k	thermal conductivity of backing material
K	efficiency of a detector
M	Mach number
q_R	radiated heat per unit area
q_E	heat conducted to the boundary layer per unit area
q_{INT}	heat conducted to the structure per unit area
T_r	local recovery temperature
T_s	temperature at the junction of the skin and detector
T_W	surface temperature
W	heat dissipated by the resistance element per unit area
ε	emissive power
σ	Stefan constant

REFERENCES

No.	Author	Title, etc.
1	McTigue, J.G. Overton, J.D. Petty, G., Jr.	Two techniques for detecting boundary-layer transition in flight at supersonic speeds and at altitudes above 20,000 feet. N.A.S.A. TND-18. August 1959.
2	Dee, F.W.	Unpublished M.O.A. Report.
3	Kordes, E.E. Reed, R.D. Dawdy, A.L.	Unpublished N.A.S.A. Report.
4	Richardson, N.R. Horton, E.A.	A thermal system for continuous monitoring of laminar and turbulent boundary-layer flows during routine flight. N.A.C.A. TN 4108. September 1957.

Printed in England for Her Majesty's Stationery Office by the Royal Aircraft Establishment, Farnborough. W.T.60.K.4.

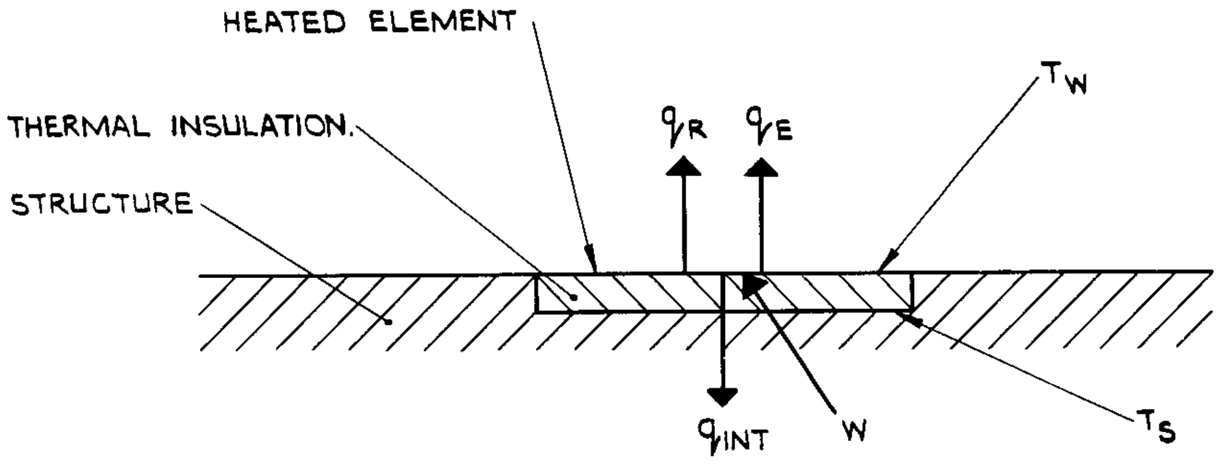


FIG 1.(a) DIAGRAM OF THE HEAT BALANCE BETWEEN THE BOUNDARY LAYER AND THE STRUCTURE

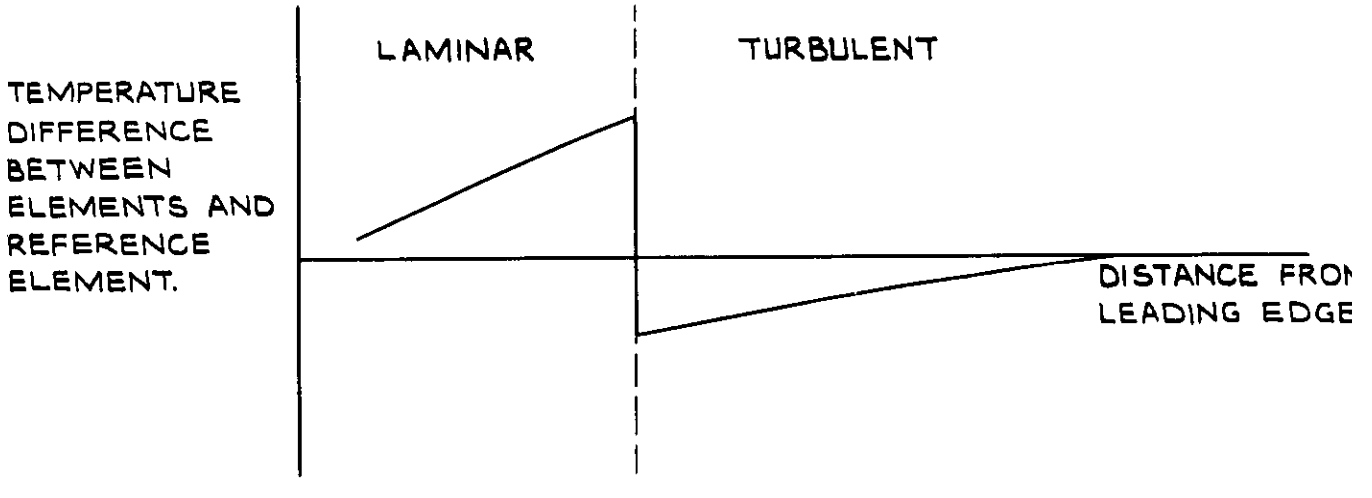


FIG 1 (b) VARIATION OF ELEMENT TEMPERATURE WITH DISTANCE FROM THE LEADING EDGE

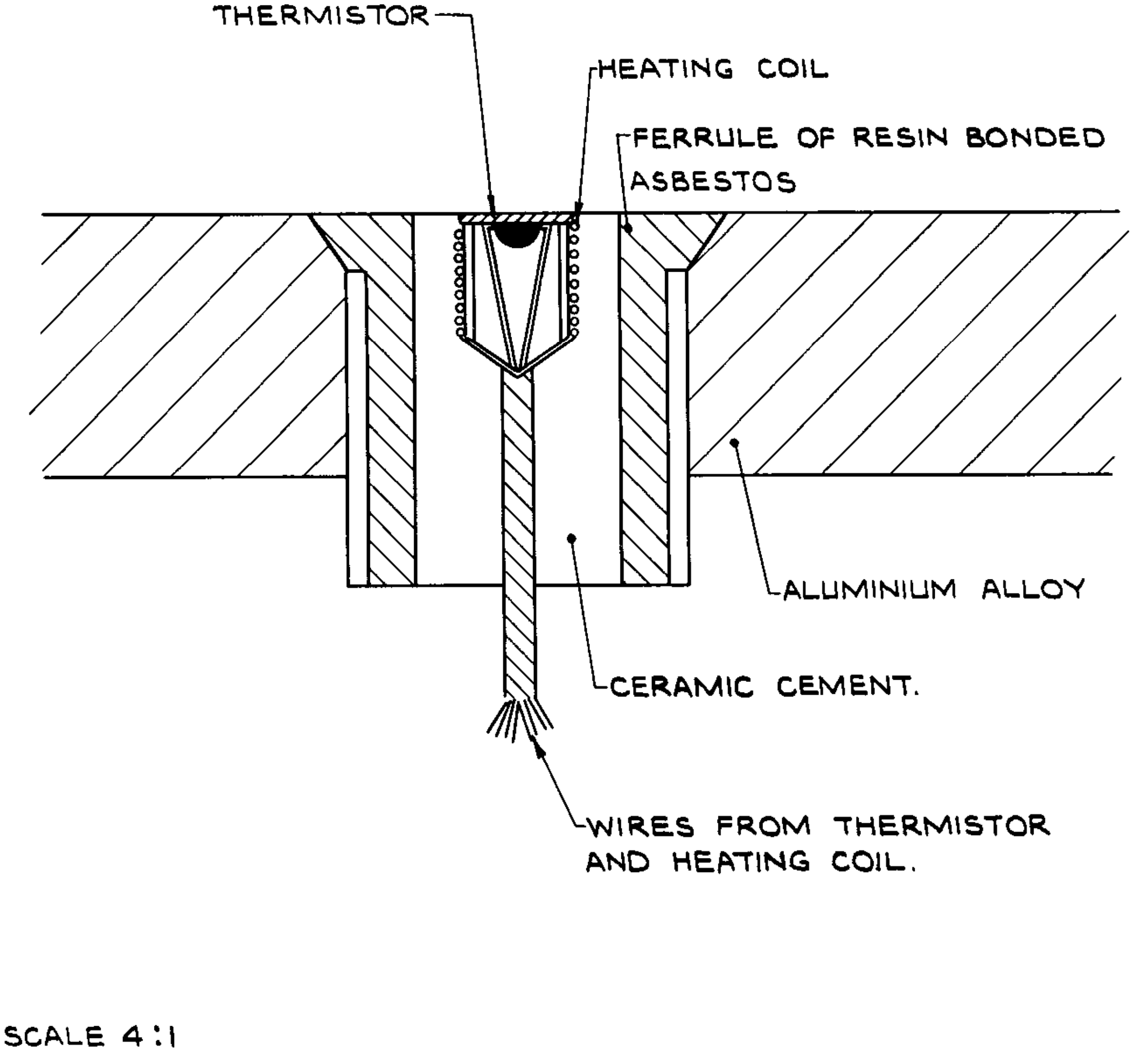
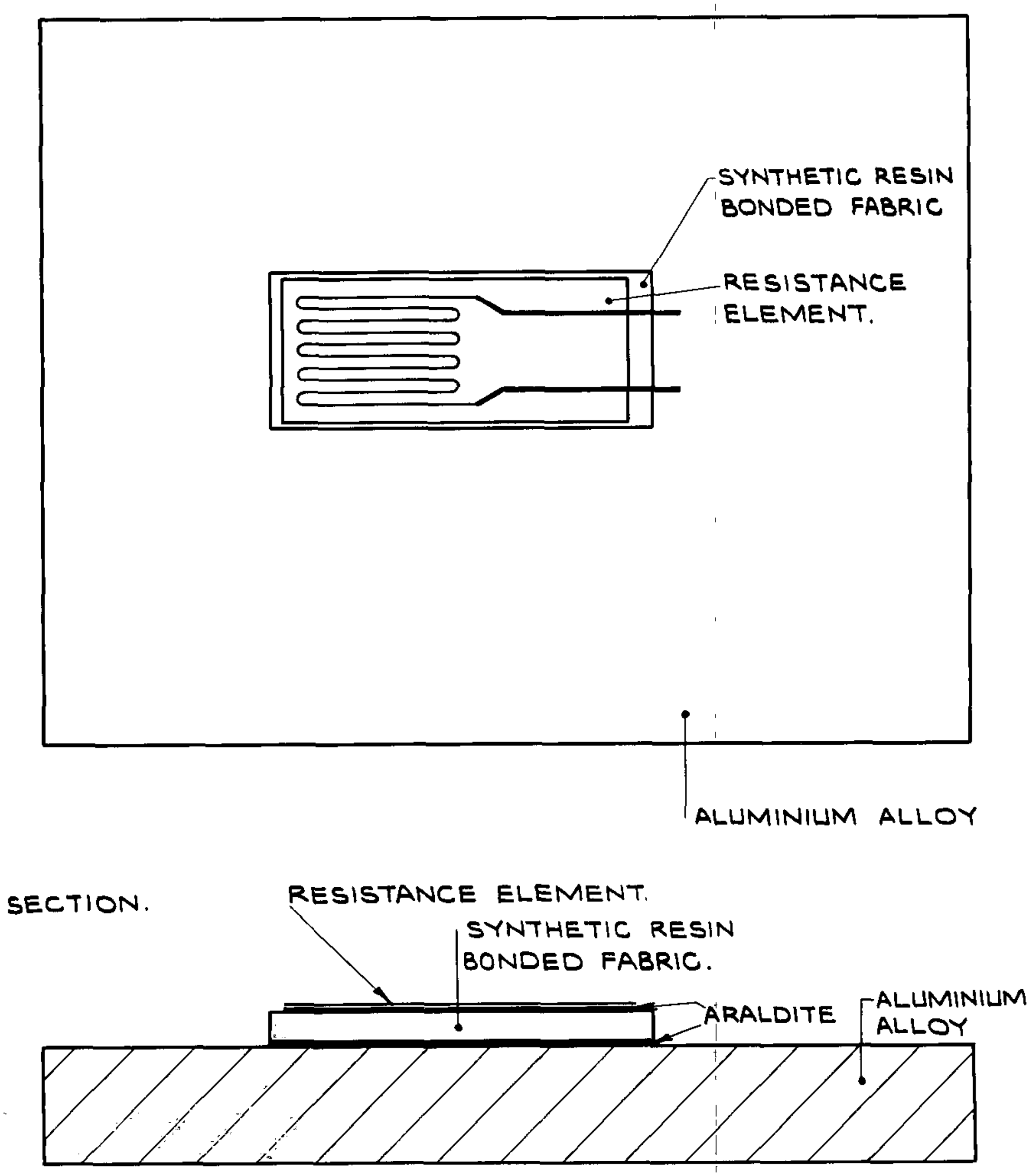


FIG.2. DIAGRAM OF THE THERMISTOR-TYPE TRANSITION DETECTOR.



NOT TO SCALE

FIG.3. RESISTANCE ELEMENT DETECTOR
USED IN LABORATORY TESTS.

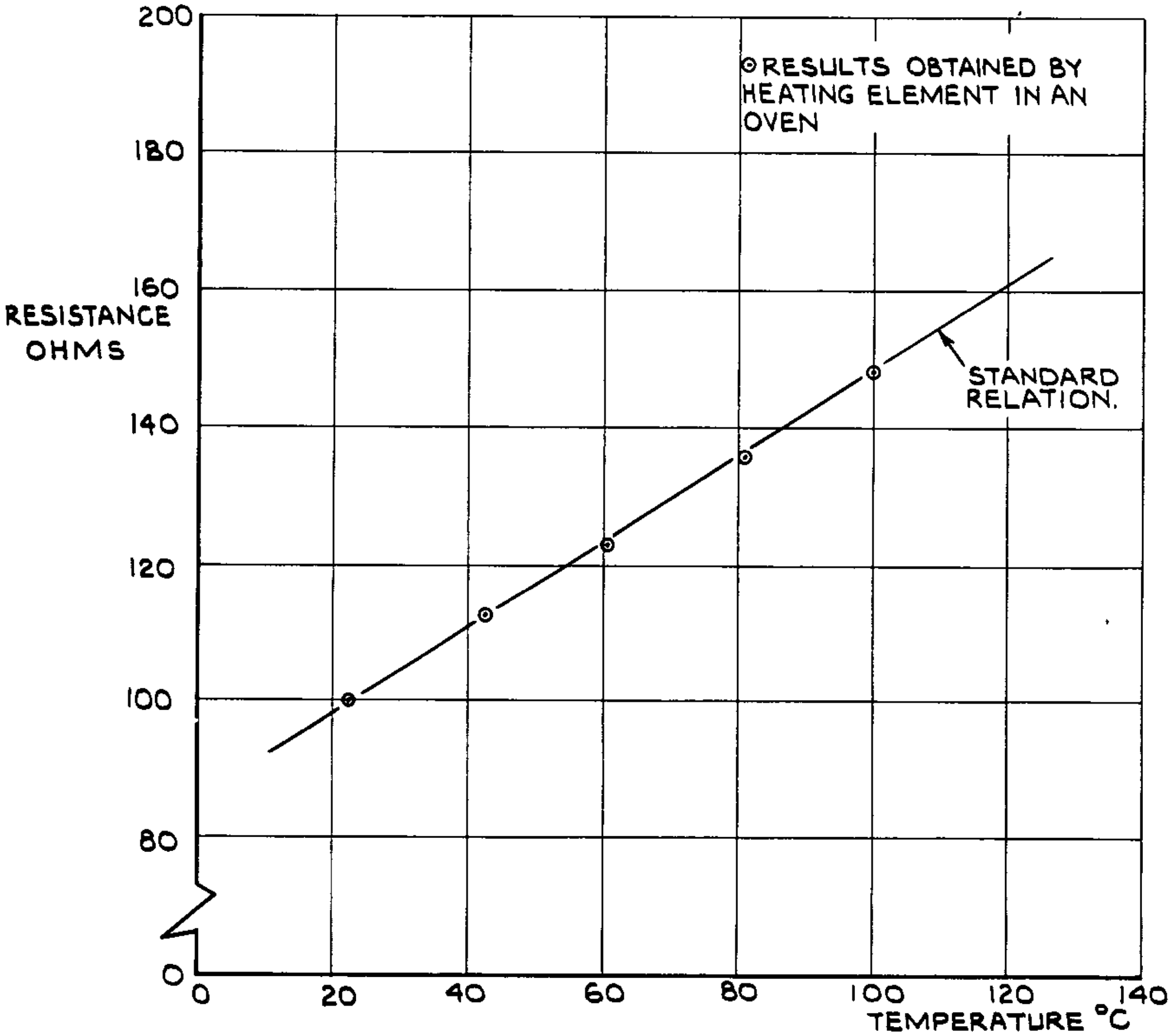


FIG. 4. RELATION BETWEEN RESISTANCE AND TEMPERATURE FOR A RESISTANCE ELEMENT.

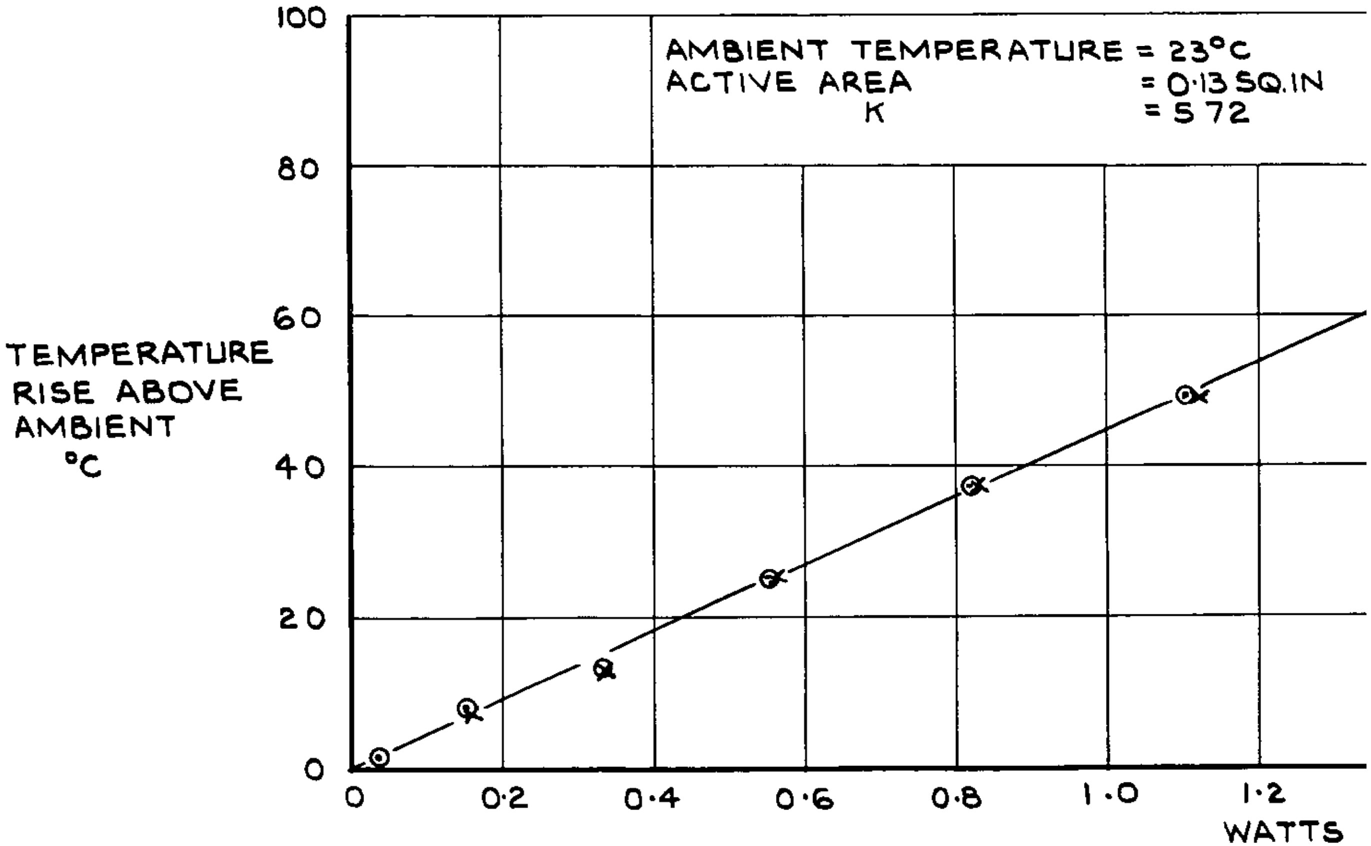


FIG.5 TEMPERATURE RISE VERSUS POWER DISSIPATED

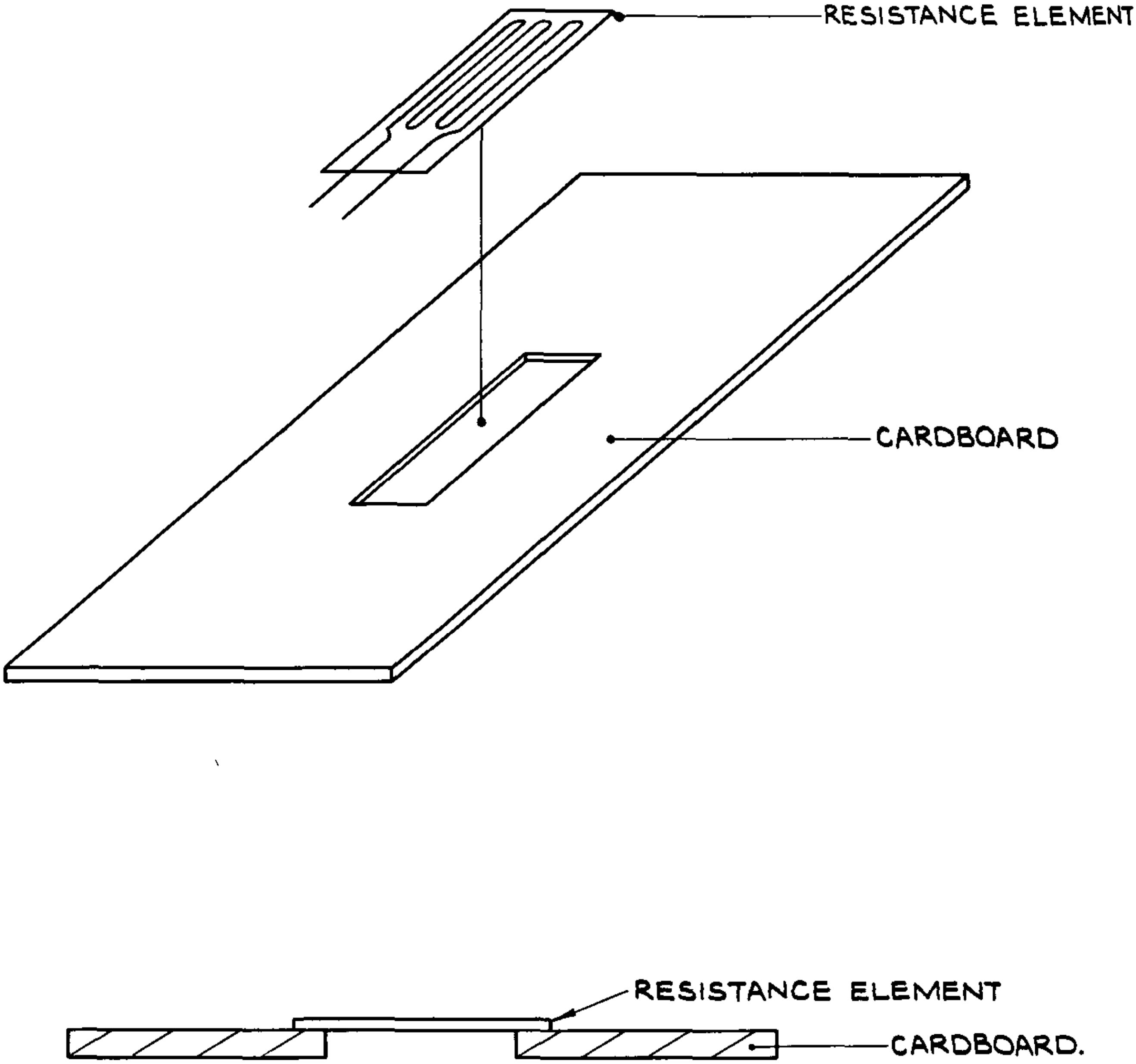


FIG.6. DIAGRAM OF A RESISTANCE ELEMENT MOUNTED ON CARDBOARD.

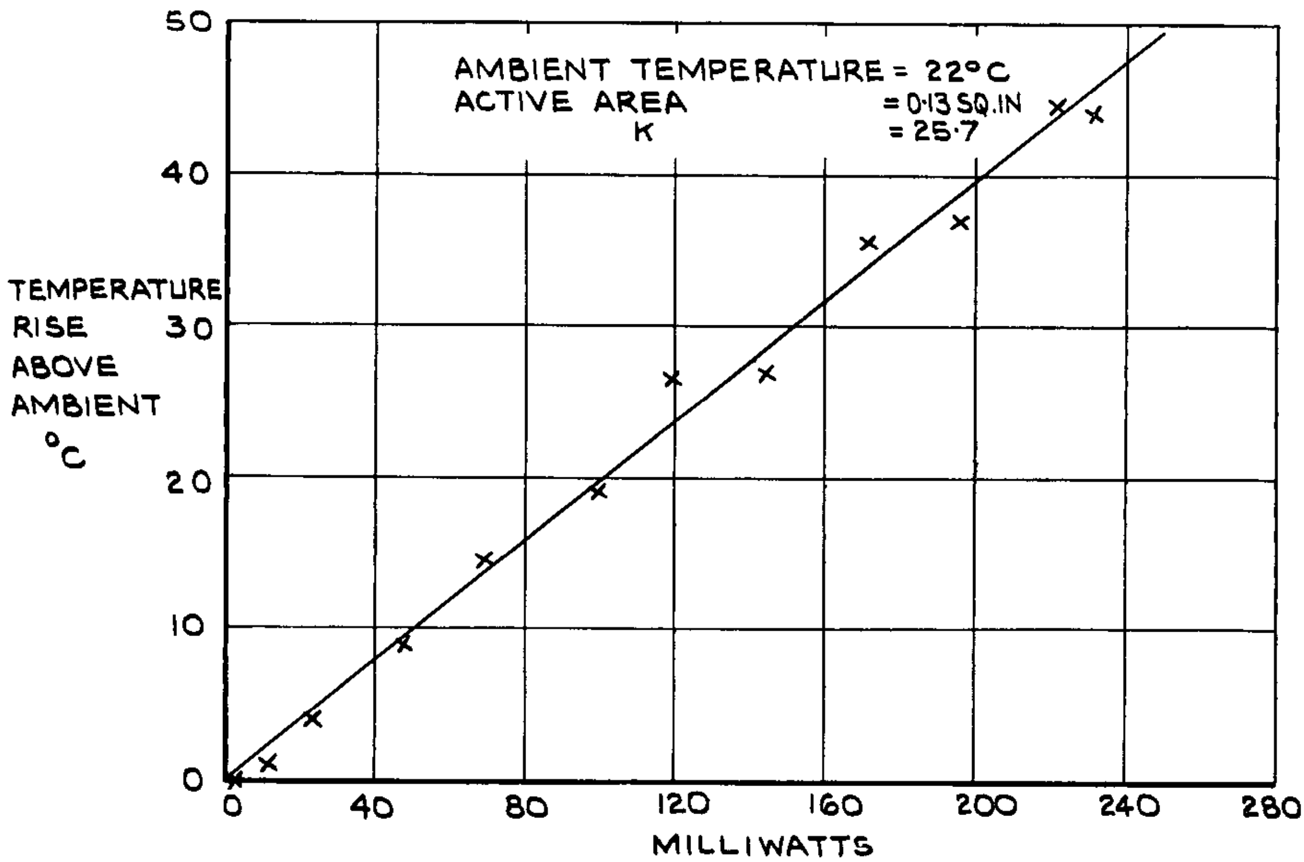


FIG. 7. TEMPERATURE RISE VERSUS POWER DISSIPATED IN A RESISTANCE ELEMENT CONDUCTING HEAT TO THE AIR FROM BOTH SURFACES.

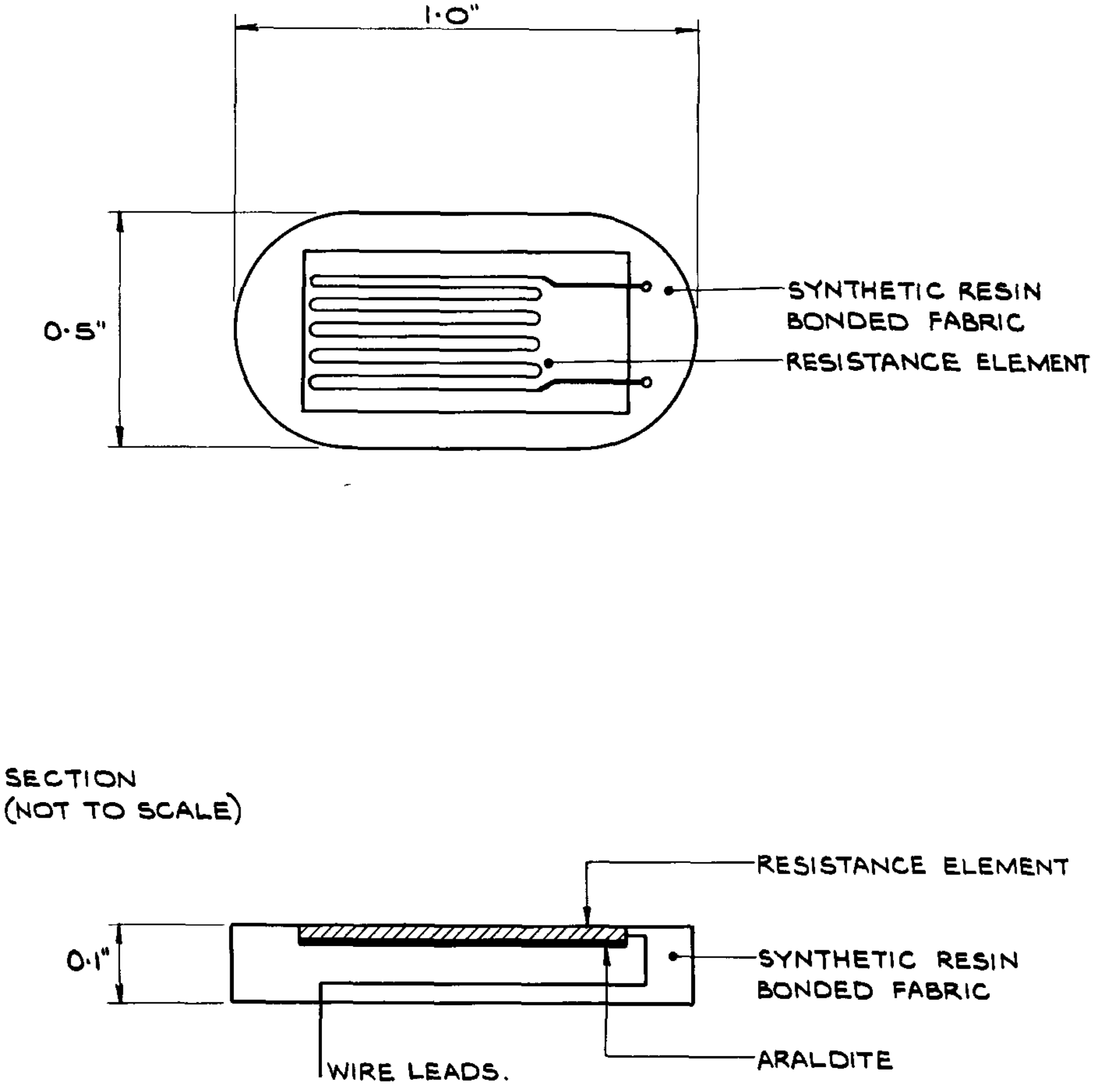


FIG. 8. RESISTANCE ELEMENT TRANSITION DETECTOR

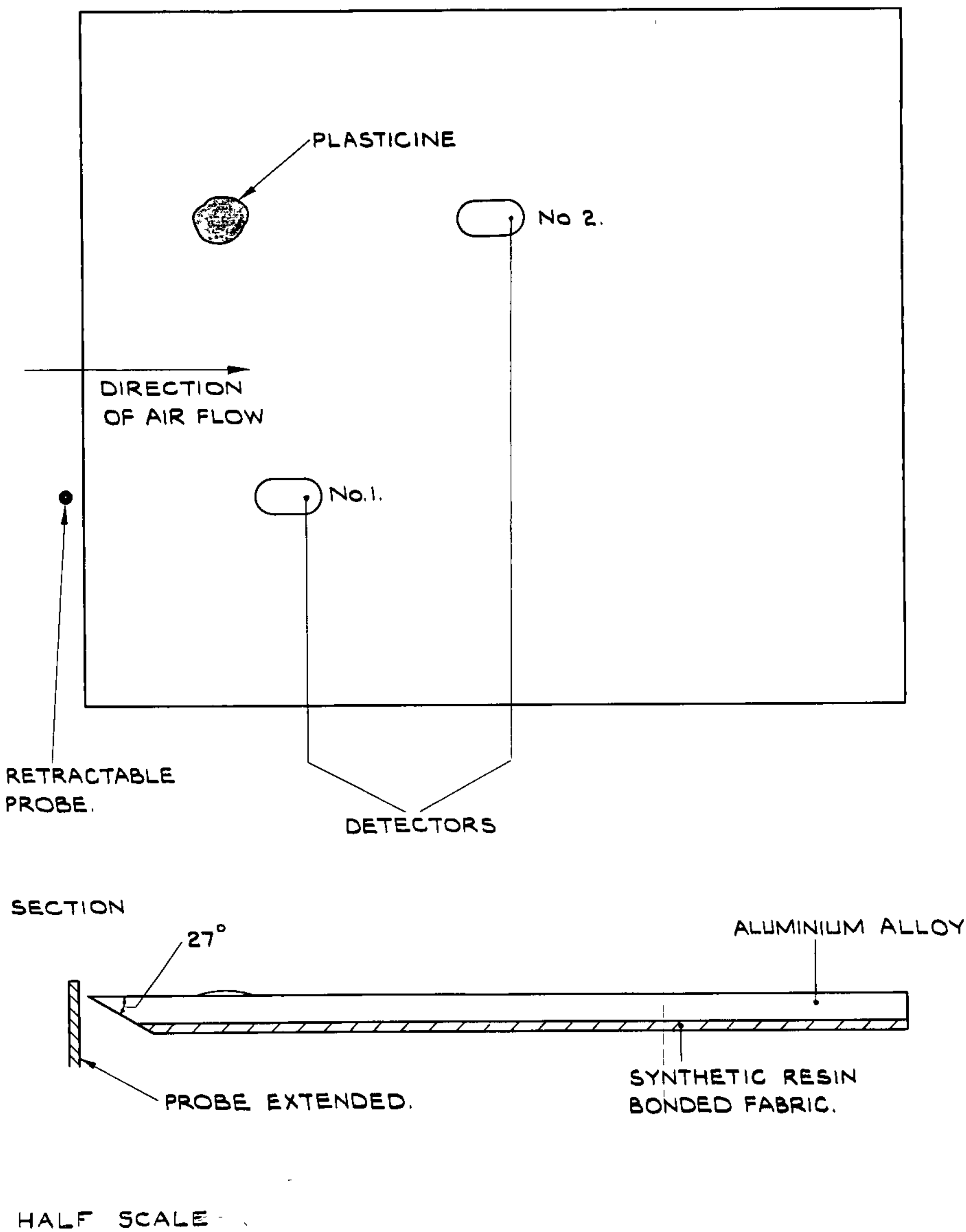


FIG 9. DIAGRAM OF THE BOUNDARY LAYER PLATE USED IN THE WIND TUNNEL TESTS

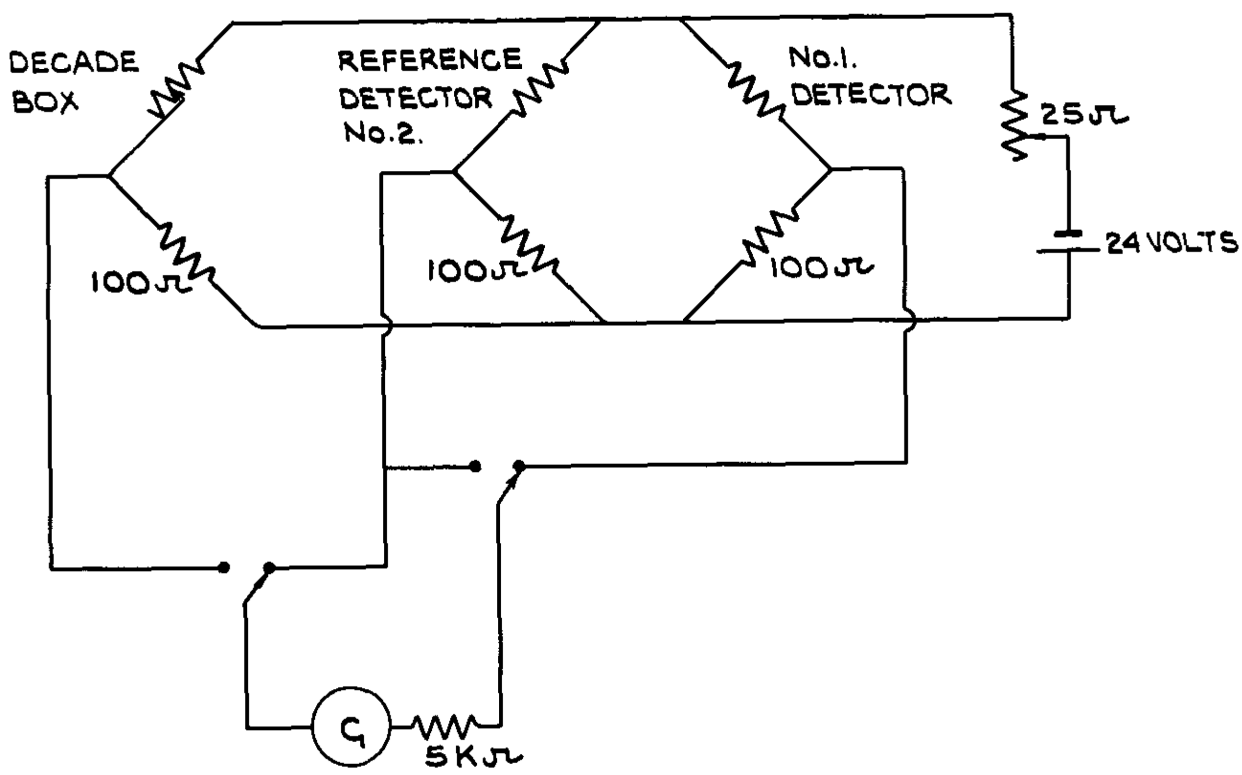


FIG.10. DIAGRAM OF ELECTRICAL CIRCUIT FOR TUNNEL TESTS ON TRANSITION DETECTORS.

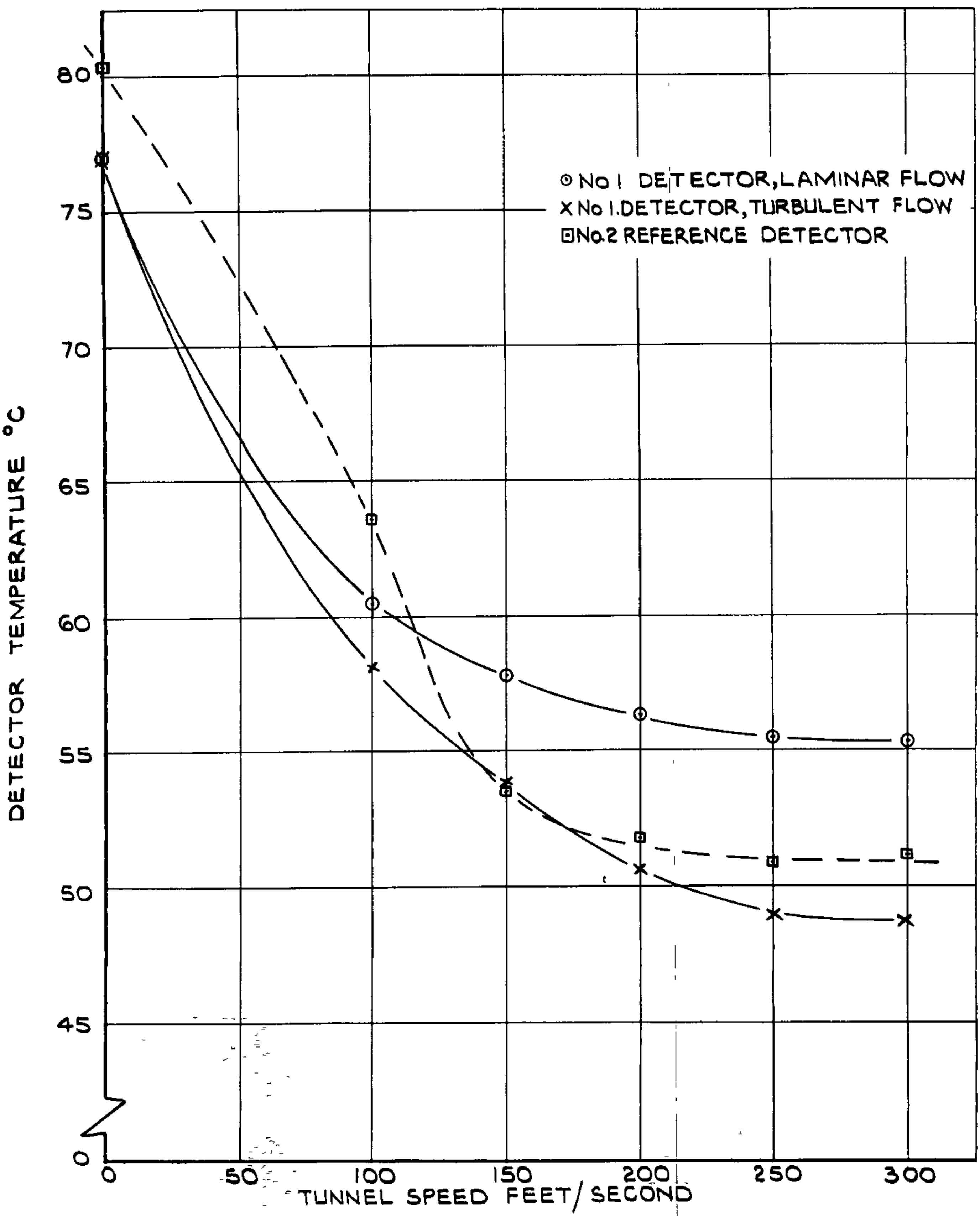


FIG. 11. VARIATION OF DETECTOR TEMPERATURE WITH TUNNEL SPEED.

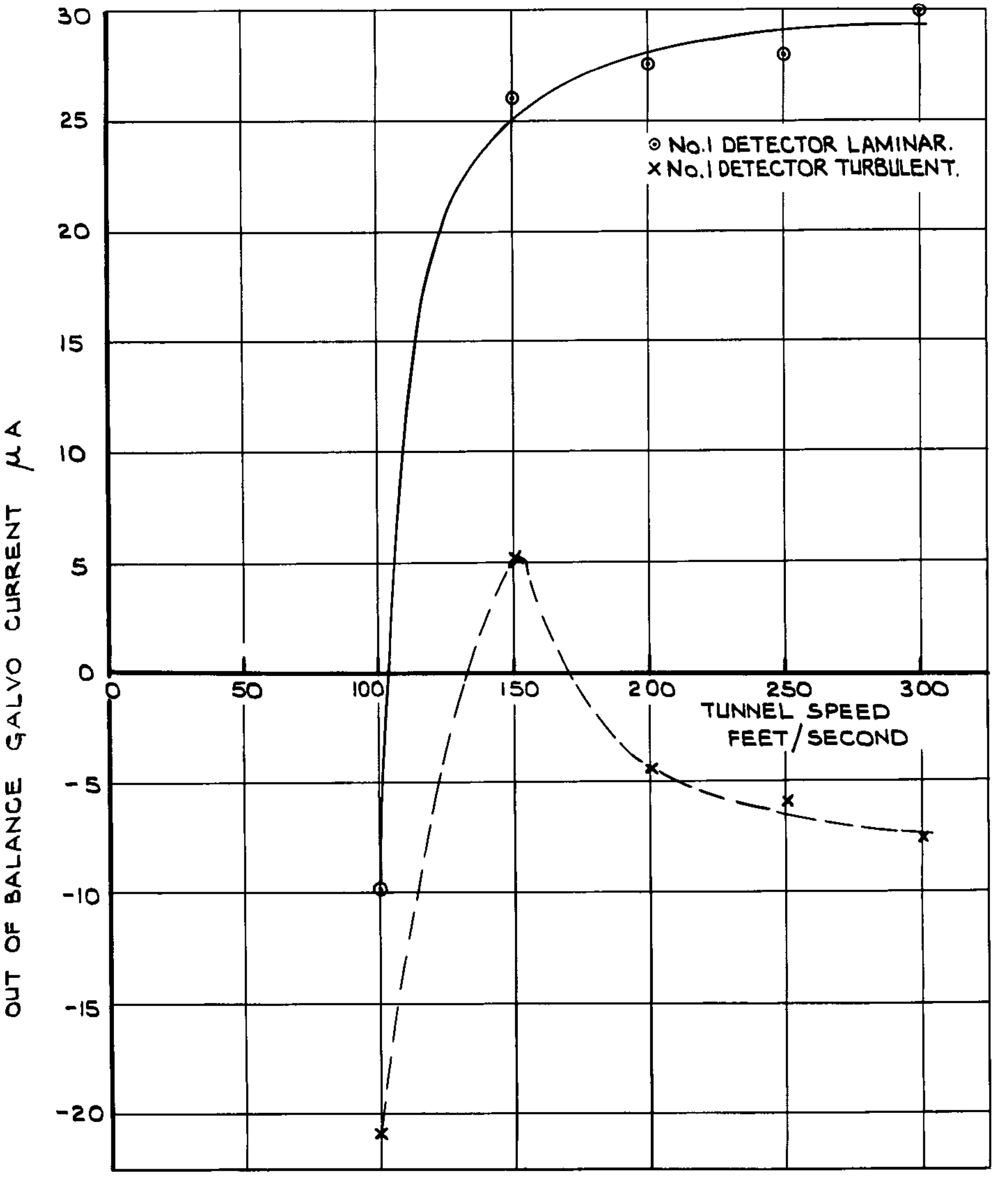


FIG.12. VARIATION OF GALVANOMETER DEFLECTION WITH TUNNEL SPEED.

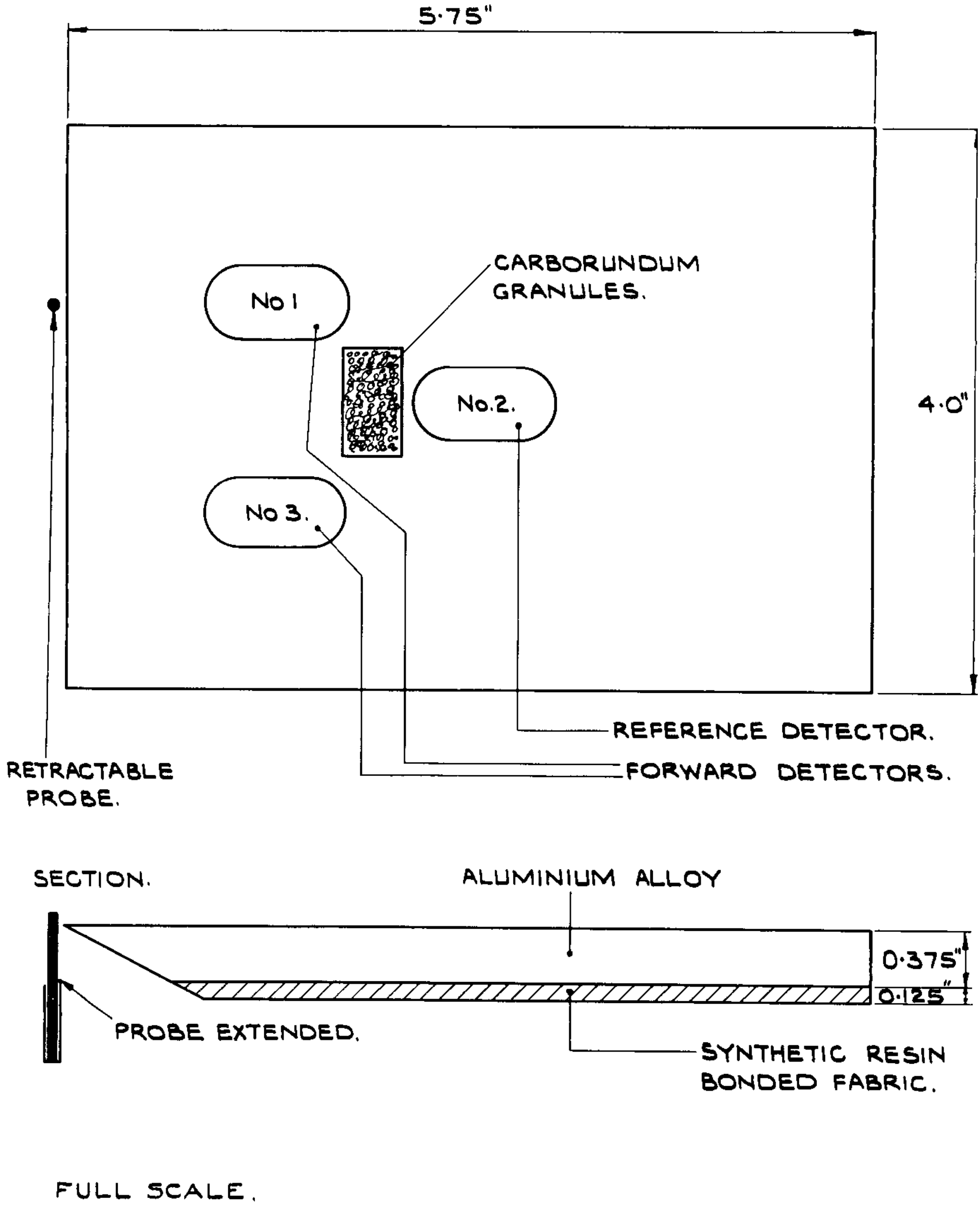


FIG 13. DIAGRAM OF THE BOUNDARY LAYER PLATE USED IN THE FLIGHT TESTS

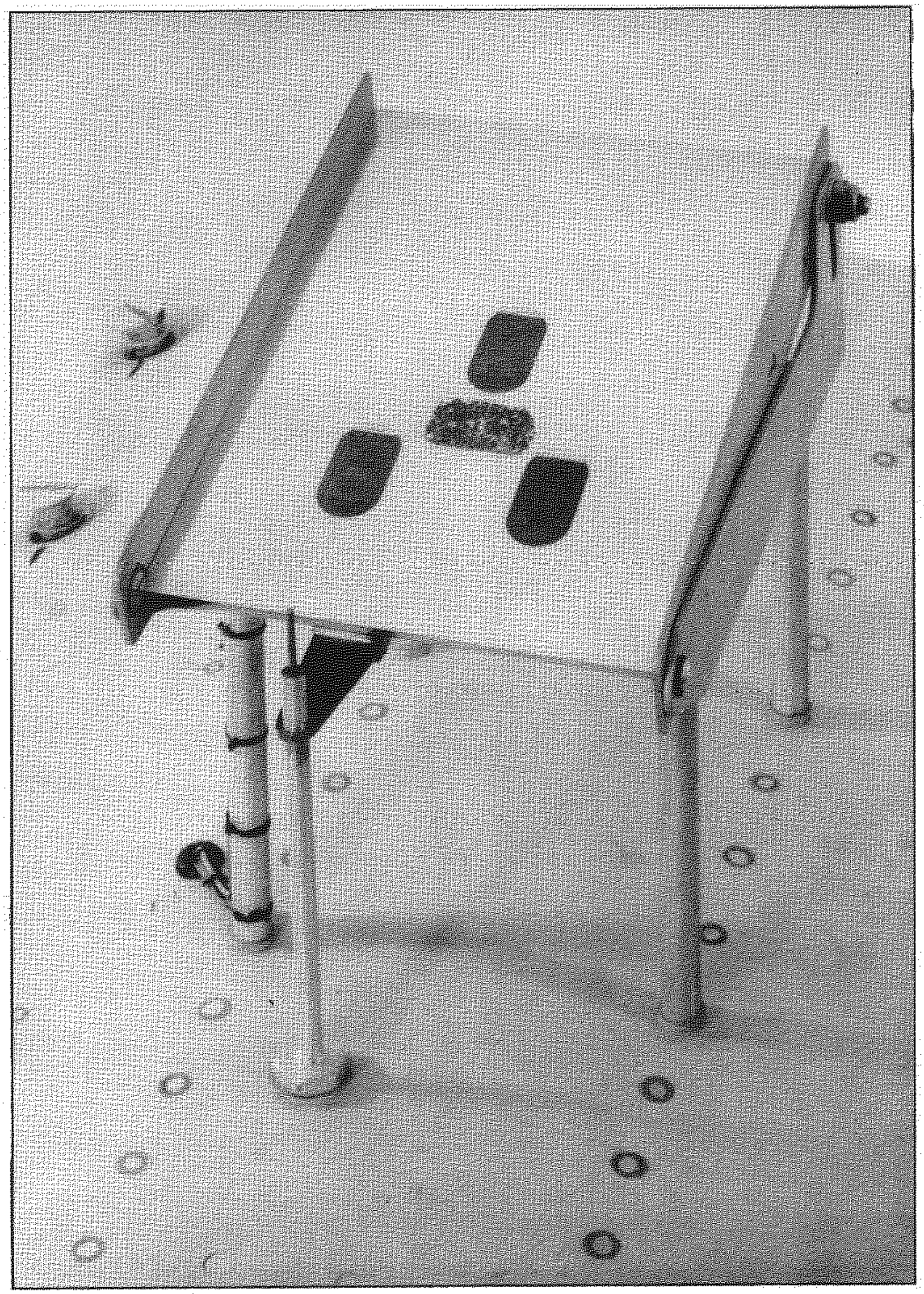


FIG.14. BOUNDARY LAYER PLATE MOUNTED ON THE AIRCRAFT PANEL

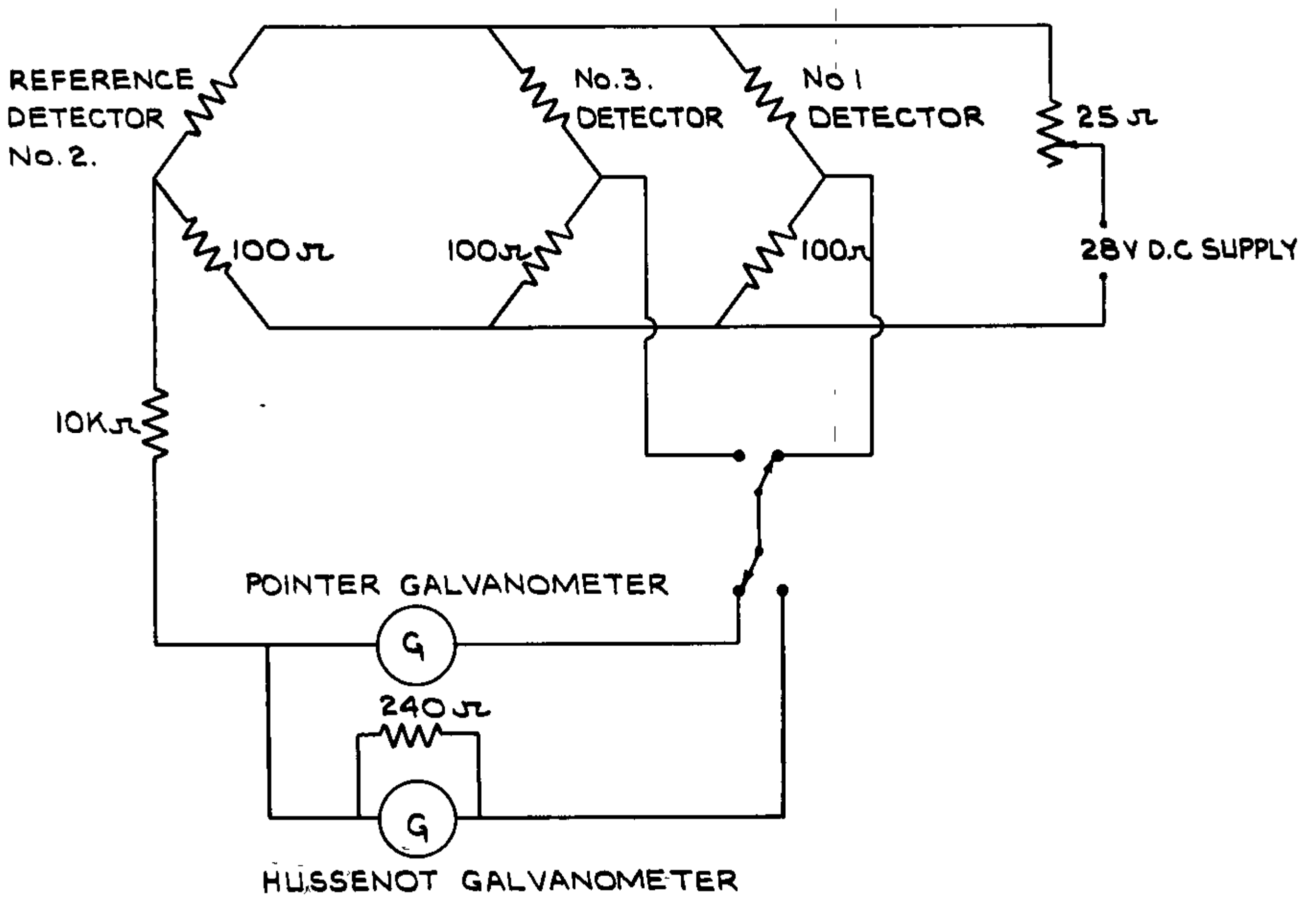


FIG 15. DIAGRAM OF THE ELECTRICAL CIRCUIT FOR FLIGHT TESTS ON TRANSITION DETECTORS.

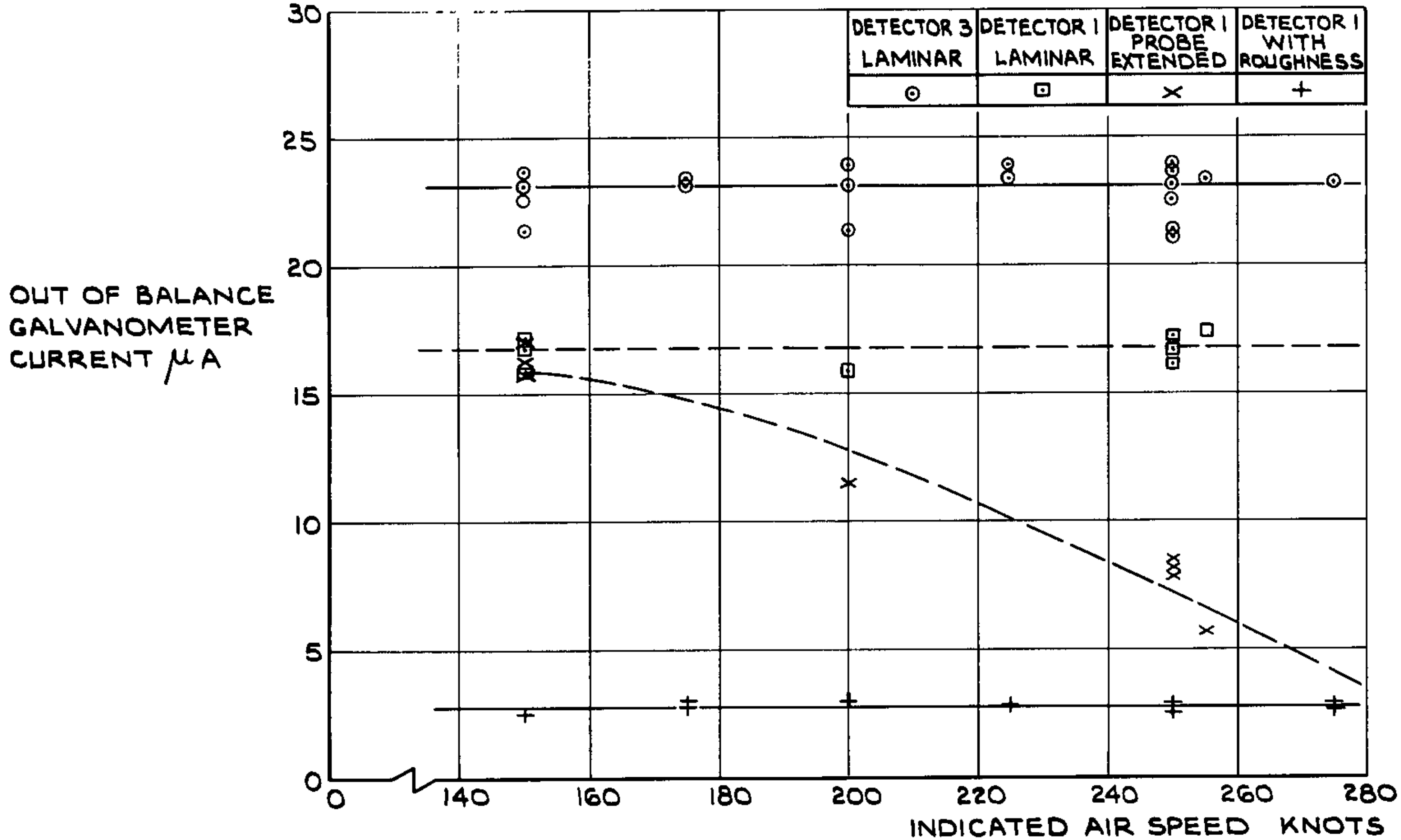


FIG.16. VARIATION OF OUT OF BALANCE GALVANOMETER CURRENT WITH INDICATED AIR SPEED.

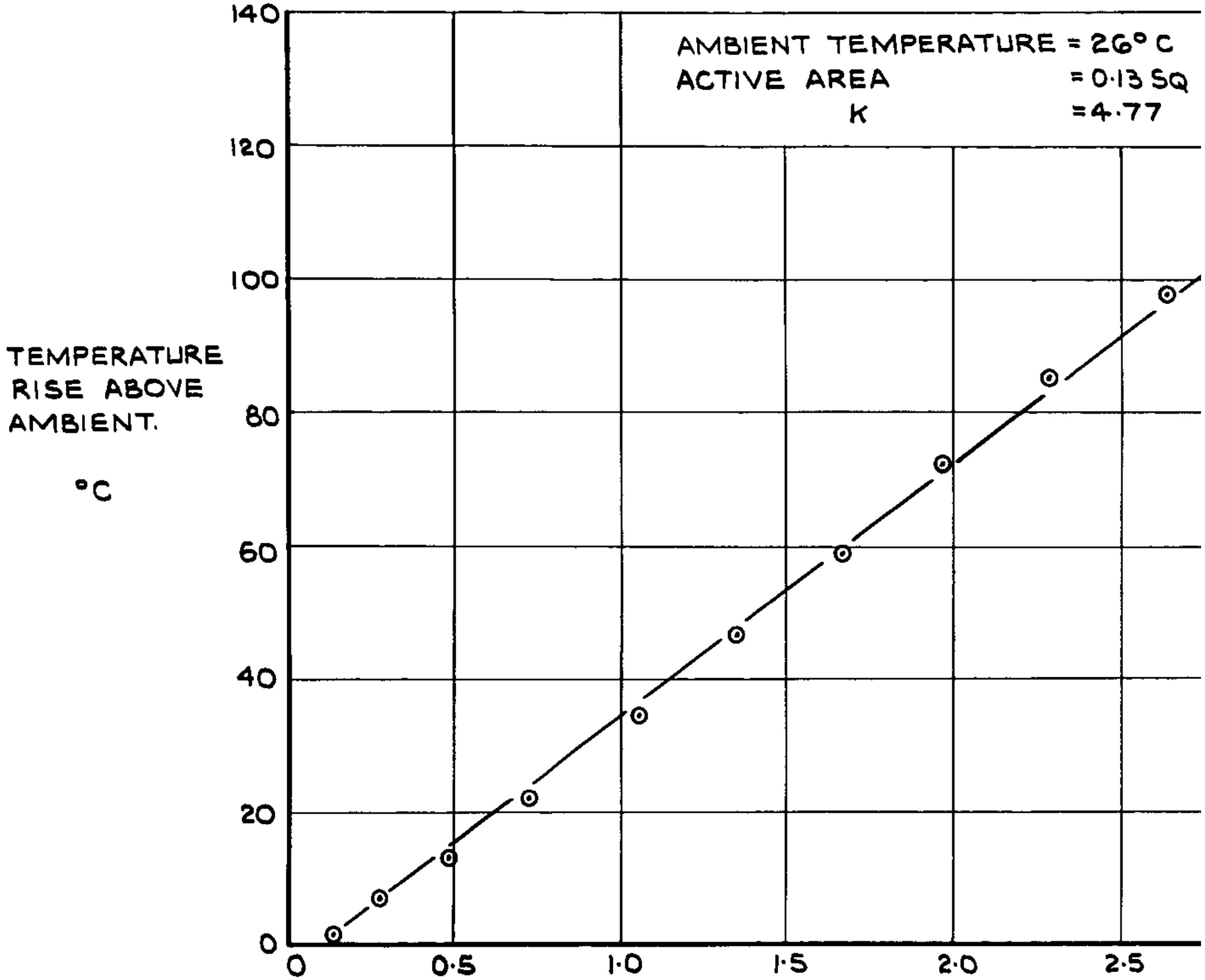


FIG 17. TEMPERATURE RISE VERSUS POWER DISS
USING ASBESTOS–FABRIC BASE MATE

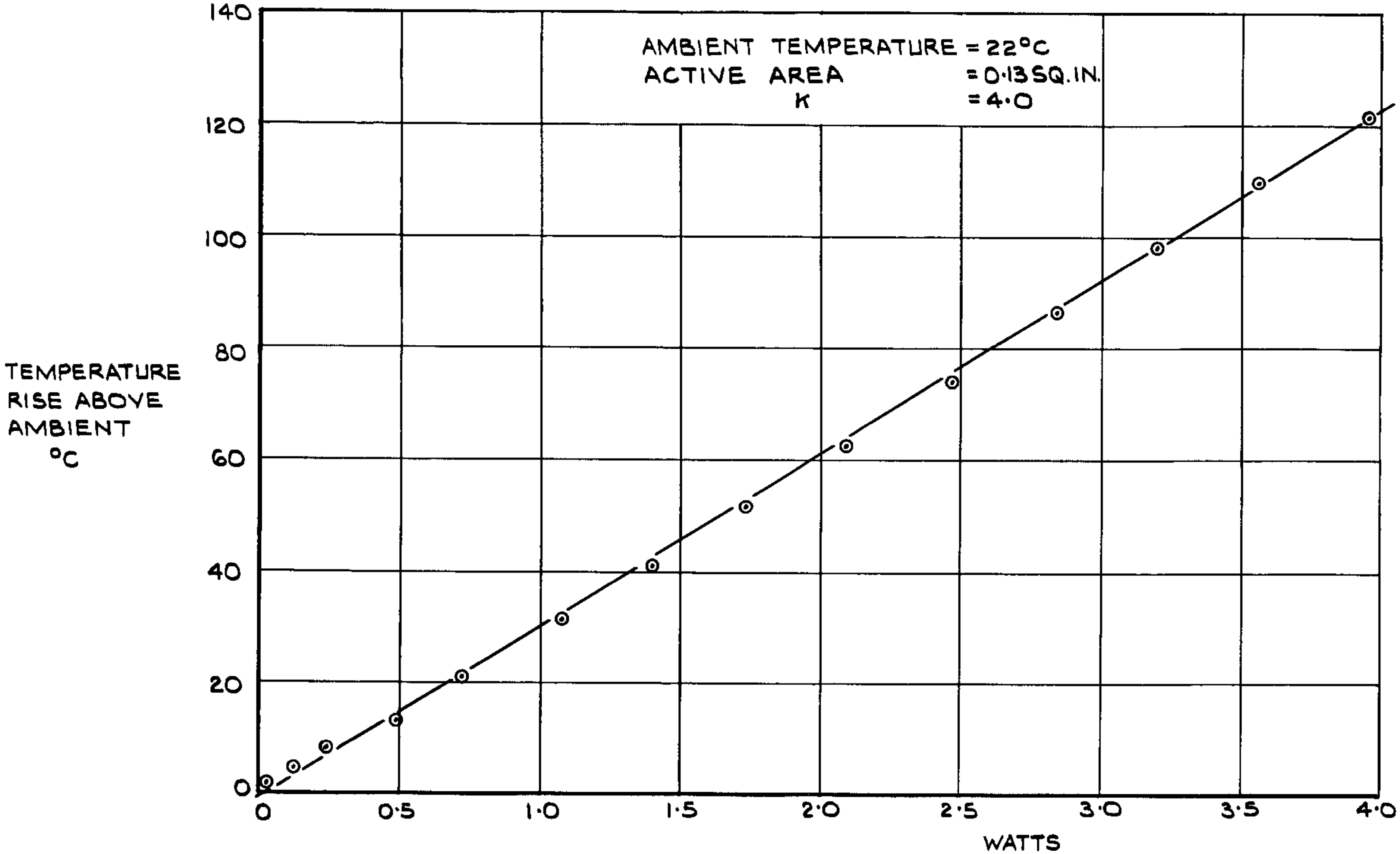


FIG. 18. TEMPERATURE RISE VERSUS POWER DISSIPATED IN A DETECTOR USING ASBESTOS-PAPER BASE MATERIAL

A.R.C. C.P. No. 781 533.6.082.7:
532.526

FLIGHT AND TUNNEL TESTS TO DEVELOP A THERMAL DETECTOR FOR DETERMINING THE BOUNDARY LAYER STATE. Cronin, Ann and Nicholas, O.P. February 1964

An investigation has been made into the suitability of a thermal detector for determining the boundary layer state on an aircraft, based on the principle of more rapid heat transfer across a turbulent, compared with a laminar, boundary layer. Following successful laboratory and wind tunnel tests, a few subsonic flight tests with the detectors mounted in a flat plate showed that they could be used satisfactorily to determine boundary layer state. This detector can be used to a working temperature of 80°C and hence could be used to give adequate signal changes up to a Mach number of 1.5 above the tropopause. Further

(Over)

A.R.C. C.P. No. 781 533.6.082.7:
532.526

FLIGHT AND TUNNEL TESTS TO DEVELOP A THERMAL DETECTOR FOR DETERMINING THE BOUNDARY LAYER STATE. Cronin, Ann and Nicholas, O.P. February 1964

An investigation has been made into the suitability of a thermal detector for determining the boundary layer state on an aircraft, based on the principle of more rapid heat transfer across a turbulent, compared with a laminar, boundary layer. Following successful laboratory and wind tunnel tests, a few subsonic flight tests with the detectors mounted in a flat plate showed that they could be used satisfactorily to determine boundary layer state. This detector can be used to a working temperature of 80°C and hence could be used to give adequate signal changes up to a Mach number of 1.5 above the tropopause. Further

(Over)

A.R.C. C.P. No. 781 533.6.082.7:
532.526

FLIGHT AND TUNNEL TESTS TO DEVELOP A THERMAL DETECTOR FOR DETERMINING THE BOUNDARY LAYER STATE. Cronin, Ann and Nicholas, O.P. February 1964

An investigation has been made into the suitability of a thermal detector for determining the boundary layer state on an aircraft, based on the principle of more rapid heat transfer across a turbulent, compared with a laminar, boundary layer. Following successful laboratory and wind tunnel tests, a few subsonic flight tests with the detectors mounted in a flat plate showed that they could be used satisfactorily to determine boundary layer state. This detector can be used to a working temperature of 80°C and hence could be used to give adequate signal changes up to a Mach number of 1.5 above the tropopause. Further

(Over)

laboratory tests on another detector of similar design using higher temperature components suggest that it could be used up to a Mach number of 1.9 above the tropopause.

laboratory tests on another detector of similar design using higher temperature components suggest that it could be used up to a Mach number of 1.9 above the tropopause.

laboratory tests on another detector of similar design using higher temperature components suggest that it could be used up to a Mach number of 1.9 above the tropopause.

C.P. No. 781

Published by
HER MAJESTY'S STATIONERY OFFICE

To be purchased from
York House, Kingsway, London W.C.2
423 Oxford Street, London W.1
13A Castle Street, Edinburgh 2
109 St Mary Street, Cardiff
39 King Street, Manchester 2
50 Fairfax Street, Bristol 1
35 Smallbrook, Ringway, Birmingham 5
80 Chichester Street, Belfast 1
or through any bookseller

C.P. No. 781

S.O. CODE No. 23-9015-81