CHAPTER 6

THERMAL CONTROLLERS, NAPIER MK. 3.

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LEADING PARTICULARS

Thermal controller, Napier Part No. 0057/506 ...	**Ref. No. 5CZ/6903**
Thermal controller, Napier Part No. 0075/508 ...	**Ref. No. 5CZ/6631**
Dimensions	*3·75 in. × 6·5 in. × 1·9 in.*
Weight	*1·41 lb.*
Power supplies	*28V d.c. and 115V 400 c/s*
Power consumption a.c. (total for both channels)	*4·5VA*
Relay rating (resistive load)	*4 amp*
Performance limits—	
Thermal controller (basic setting)	*±1 deg. C of operating temp.*
Thermal controller and temperature sensing element (system error)	*±6 deg. C of cut-out temp.* *±8 deg. C of cut-in temp.*

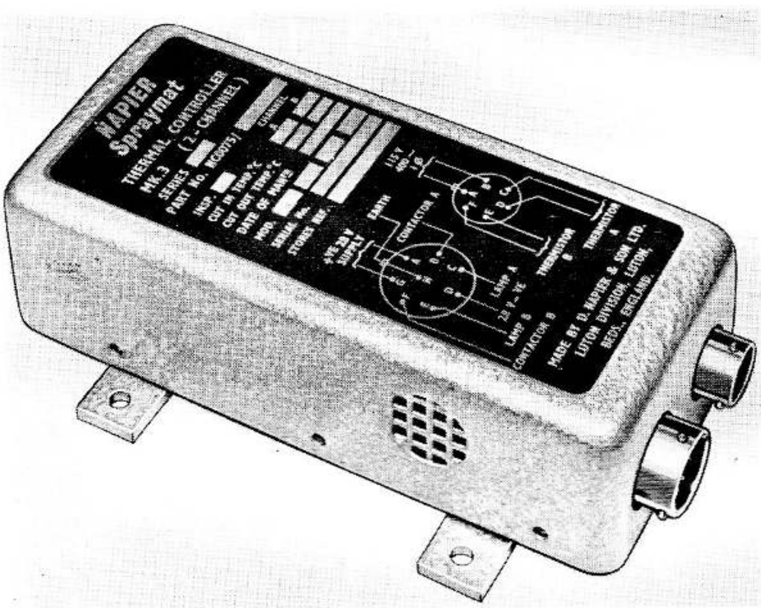


Fig. 1. Thermal controller Mk. 3

Introduction

1. The Napier Mk. 3 thermal controllers are twin-channel transistorized units designed to operate in conjunction with a temperature sensing element and are used to prevent overheating of Napier, Spraymat, surface heaters. They are available in a range of operating temperature settings, identifiable by the Part No., as given in Table 1.

2. This chapter deals only with the Mk. 3 thermal controllers in which the circuit design and function of each channel in a controller is similar, the following information is therefore applicable to any channel. General information on the Napier de-icing system is given in A.P.4343, Vol. 1, Sect. 21 and details of the heaters and of heater repair are given in A.P.1464D, Vol. 1, Part 2, Sect. 4 to which reference should be made.

DESCRIPTION

General

3. A Mk. 3 thermal controller is shown in fig. 1; each controller incorporates two separate channels designated A and B and each channel comprises an a.c. bridge network, a transistorized a.c. amplifier, a phase discriminator, a d.c. output stage and a hermetically sealed relay. The components for the circuits are contained on a printed circuit assembly mounted on a flanged, light-alloy, ventilated chassis. Four wire-wound resistor bobbins forming part of the a.c. bridge are secured directly to the chassis, each by a single screw and locknut to facilitate removal. A deep drawn brass cover incorporating two perforated ventilation discs encloses the chassis and all components.

4. The printed circuit assembly consists of an upper and a lower printed circuit board which are mounted on six light-alloy pillars, six 4 B.A. screws screw into the base of the pillars and secure the assembly to the chassis. The pillars also accommodate six of the transistors and serve as heat-sinks for them. The upper board carries the components for the second stage of the a.c. amplifier, the phase discriminator, the d.c. output stage, the relay for each channel, the power transformer and the power bridge-rectifier circuit components. Components for the first stage of the a.c. amplifier are carried on the lower board with the first stage transistor VT1 secured under a clip on top of the board. The two circuit boards complete with their components are coated with epoxy resin for protection against dust and moisture, and also for anti-vibration support. Electrical connection is made by two Bendix-Thorn (Pigmy) plugs mounted on a bracket at one end of the chassis.

Circuit

5. The power supply for each channel is provided by a 24V centre-tapped secondary winding, winding C, of the power transformer through a bridge rectifier circuit comprised of silicone junction diodes, D1A, D1B, D2A and D2B. The maximum power delivered is 50mA at 30V and is drawn when the output relay is energized. Smoothing in each channel is provided by capacitor C9. Winding C also provides the half-wave reference signal to the collector of the phase discriminator via rectifier D5 and the RC network of R13, R15 and C8.

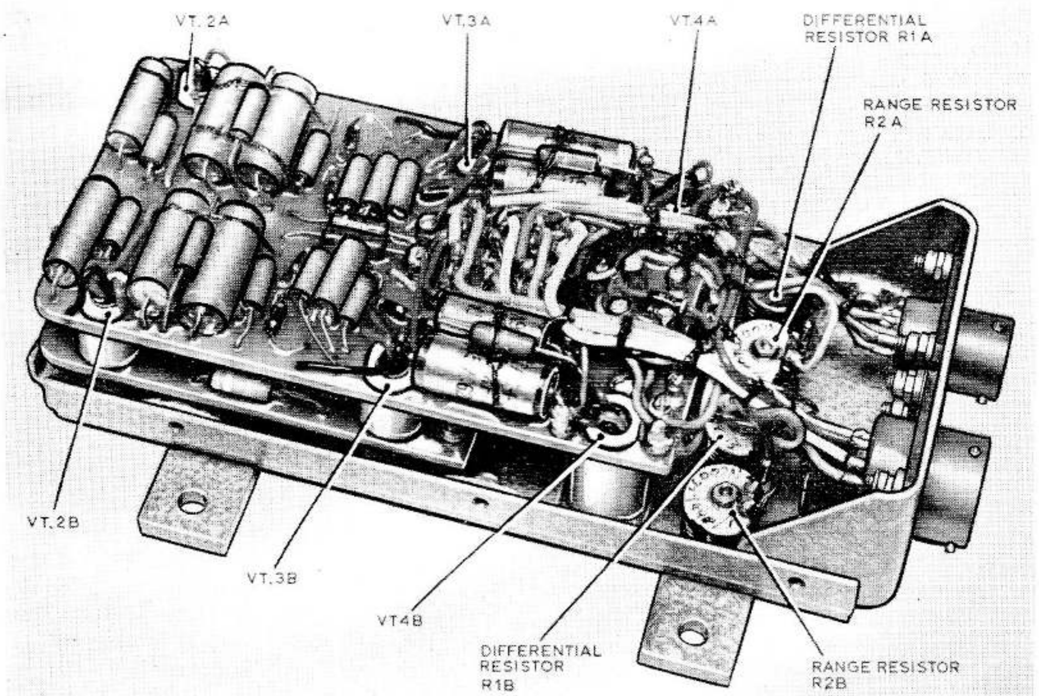


Fig. 2. Controller with cover removed

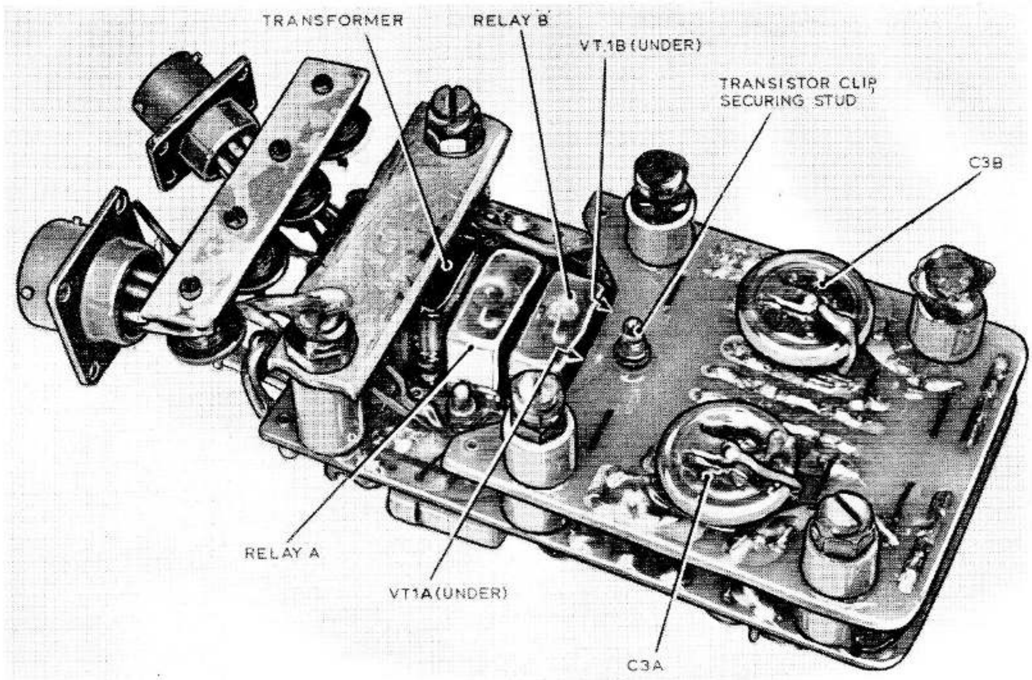


Fig. 3. Underside view of circuit board assemblies

6. The operation of each channel is controlled by a temperature sensing thermistor which has a nominal resistance of 5000 ohms at 20 deg. C. and a negative temperature coefficient, i.e. the resistance falls with increased temperature and rises with decrease in temperature. Change of the thermistor resistance affects the balance of a bridge network and produces a voltage having a phase angle normal or reversed to the reference voltage at the phase discriminator.

7. The sensing bridge network is composed of one of the 1V centre-tapped secondary windings of the transformer T1 (A or B as applicable), the series connected differential resistor R1 and range resistor R2, and the thermistor sensing element. The halves of the transformer windings form the ratio arms whilst the resistors and the thermistor form the balancing arms. Power to be dissipated in the thermistor sensing element is limited to 4·0mW in order to reduce thermistor self-heating resistance changes to an acceptable level. The output of the a.c. bridge is fed from the junction of resistor R2 and the thermistor, via a polarized capacitor C2, to the base of transistor VT1 in the first stage of the two-stage a.c. amplifier. The two-stage amplifier comprising transistors VT1 and VT2 supplies half-wave signals, in the phase determined by the bridge output, to the base of the phase discriminator, transistor VT3.

8. The collector of the phase discriminator is supplied with half-wave reference signals, originating in the secondary winding C of the transformer T1, via diode D5 and the RC network. The function of the RC network is to limit the reference signal period to less than a half-cycle in order to cut-off phase changes of inconstant value, due to transient signals from the sensing bridge, at the limits of the control temperature range. This eliminates the short duration pulses which would otherwise pass to the relay causing it to chatter and apply power intermittently to the Spraymats in the HEAT OFF conditions. Diode D4 is connected between the collector of transistor VT3 and the base of transistor VT4 in order to prevent the smoothing capacitor C9 discharging through transistor VT3 between the collector supply pulses.

9. When the signals applied to the base and to the collector of the phase discriminator are of like phase it conducts and effectively short circuits the base and emitter of the output transistor VT4. The transistor VT4 is then cut-off (non-conductive) and the

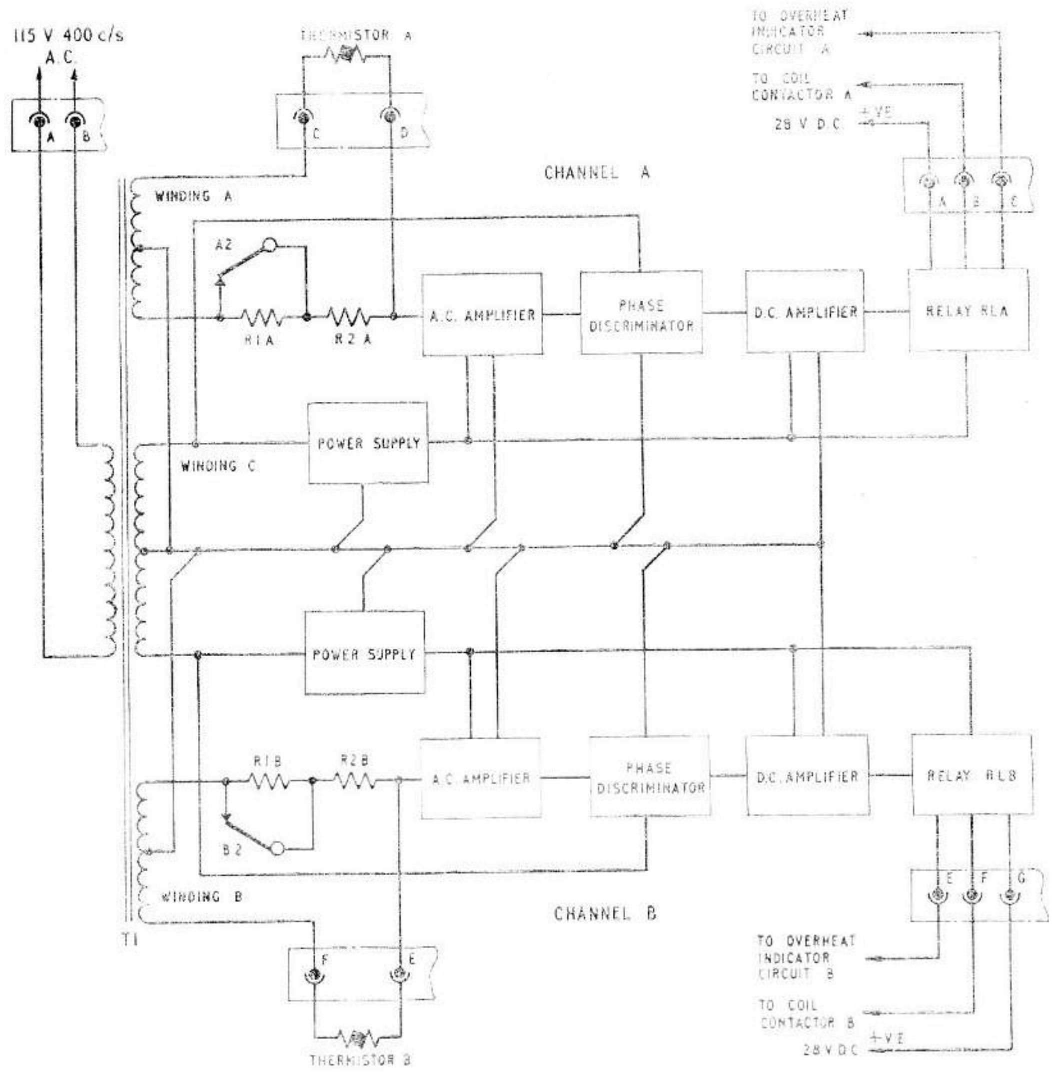


Fig. 4. Block schematic diagram

supply to the coil of the relay broken. With the relay de-energized a 28V positive supply is connected to the coil of the heater contactor in the aircraft circuit. The heater mats are now operative and this is known as the HEAT ON or CUT IN condition.

10. When the signals applied to the phase discriminator are of opposite phase it is cut-off and the base of the output transistor VT4 is biassed to the conducting point. The output relay is now energized and the supply to the heater contactor broken by the action of the changeover contacts which make the positive supply to a OVERHEAT warning indicator. This is known as the HEAT OFF or CUT OUT condition.

11. The cut-out (HEAT OFF) temperature for a channel is set by the wire wound resistor R2, which is wound to the equivalent resistance value of the thermistor at the temperature required. The cut-in (HEAT ON) temperature for a channel is set by the wire wound resistors R1 and R2 in series, resistor R1 being wound to the difference in resistance between resistor R2 and the thermistor resistance at approximately 1 deg. C above the required cut-in temperature.

12. The hermetically sealed relay, R4, carries one set of changeover contacts, RL/1, and one set of normally closed contacts, RL/2. The change-over contacts control the contactor in the power supply to the Spraymats and the overheat warning circuit, whilst the normally closed contacts short circuit the resistor R1 during the HEAT ON condition.

OPERATION

Heat on

13. Initially the temperature being monitored by the channel sensing element is below the preset cut-out temperature of the controller and the resistance of the thermistor will be high giving a signal at the base of the phase discriminator in phase with the reference signal on the collector. The phase discriminator will thus conduct short circuiting the output transistor. The output relay is de-energized and power supplied via the contactor to the Spraymats, with resistor R1 short circuited by the normally closed contacts. This condition is the HEAT ON or CUT IN condition, during which heat is supplied to the Spraymats and the channel of the controller is cut-in shorting the output transistor.

Heat off

14. The temperature monitored by the sensing element will rise during the HEAT ON period and the thermistor resistance will subsequently fall. When the temperature of the Spraymat rises to the preset cut-out temperature of the controller, the resistance of the thermistor will be low and the signal at the base of the phase discriminator of opposite phase to that of the reference signal on the collector.

15. The phase discriminator will thus be non-conductive and the output transistor conductive. The output relay is thus energized and the changeover contacts will changeover breaking the supply to the heater contactor and initiating an OVERHEAT warning signal. The normally closed contacts of the relay will open inserting resistor R1 in series with resistor R2. This condition is the HEAT OFF or CUT OUT condition during which supply to the heater mats is removed and the channel of the controller is cut-out allowing the output transistor to conduct.

Cut-in, heat on condition

16. During the HEAT OFF condition the temperature of the Spraymat will fall and the thermistor resistance will subsequently rise. When the temperature rises to 1 deg. C above the nominal cut-in temperature for the channel the thermistor resistance will be of a value higher than the combined resistances of R1 and R2 and a negative signal on the base of the phase discriminator will de-energise the relay. Heat will be applied to the Spraymats once more and the OVERHEAT warning signal cancelled.

TABLE 1

Operating range and parallel resistance curve references

Part No.	Channel A				Channel B			
	Temperature range (Deg. C)		Resistance curve (Appendix)		Temperature range (Deg. C)		Resistance curve (Appendix)	
	Cut-out	Cut-in	Cut-out	Cut-in	Cut-out	Cut-in	Cut-out	Cut-in
NC.0075/506	70	40	3	2	80	40	4	2
NC.0075/508 (Pre Mod. D1234)	80	35	4	1	80	35	4	1
NC.0075/508 (Post Mod. D1234)	80	40	4	2	80	40	4	2

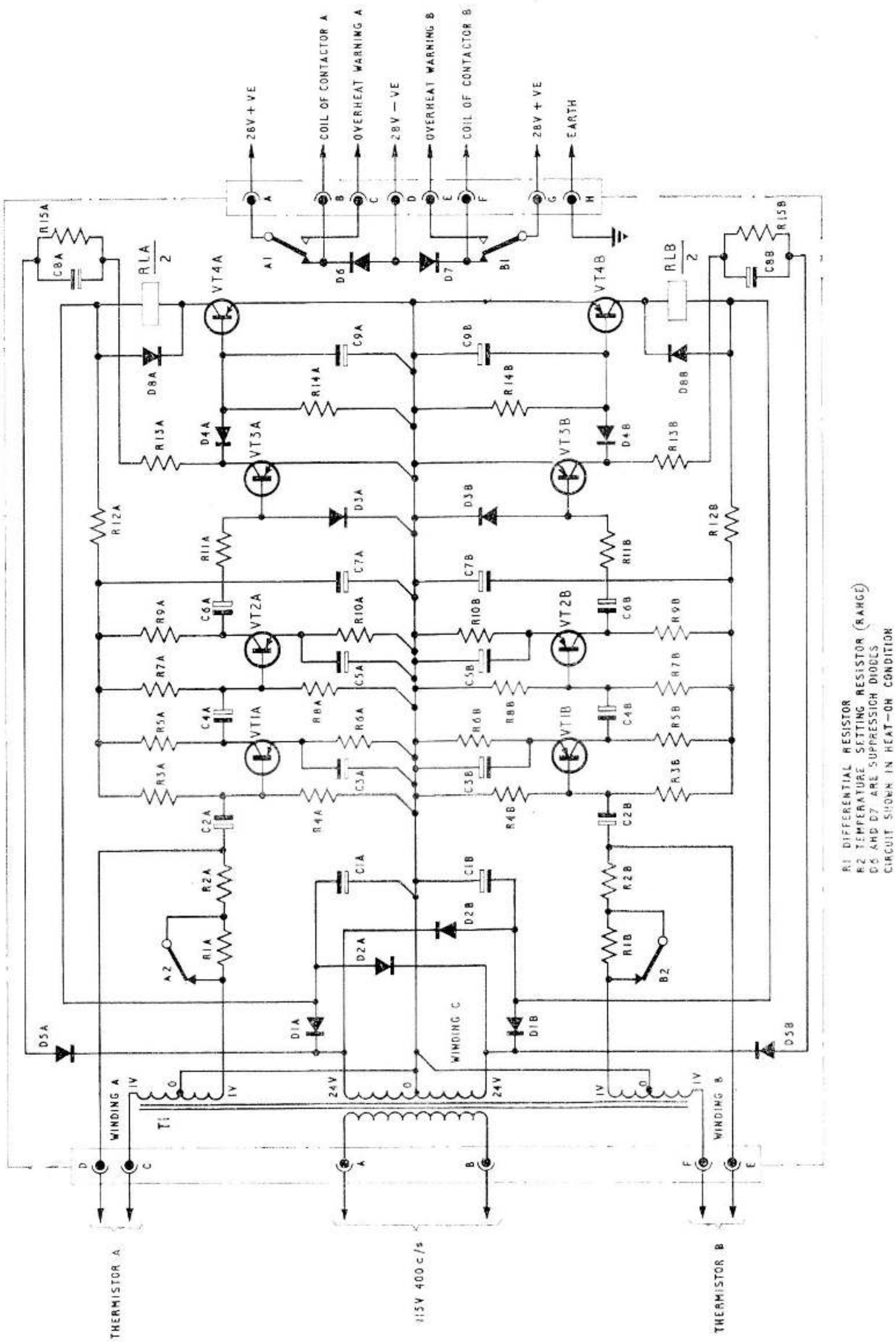


Fig. 5. Circuit diagram

SERVICING

17. The circuit boards and components, and the range and difference resistor bobbins, are coated with two coats of epoxy resin (lacquer, AR1042, mixed with catalyst, AR1041, in the ratio 50–50 by volume) which should not be removed. Servicing is therefore restricted to examination for freedom from damage and visual inspection of the components with the cover removed for signs of overheating, tracking or the ingress of oil or moisture.

Functional test at aircraft

18. A functional test of a controller and its associated sensing element whilst installed in an aircraft can be made by disconnecting the controller from the aircraft circuit and connecting it to a test circuit as shown in fig. 6. The connections to the thermistor may be made at a convenient terminal block or to the appropriate pins of the aircraft six-pole socket.

19. Prior to the commencement of the test refer to Table 1 and determine the appropriate parallel resistance curve for the cut-in and cut-out temperature for each channel of the controller. These curves (App. 1–4,) show the resistance which is connected in parallel with the thermistor for test purposes and the values derived are not suitable for use as a substitute for the thermistor. The location of the thermistor sensing element on the heater component should also be ascertained from the aircraft handbook and the ambient surface temperature of the heater at this point recorded.

20. (1) Set each decade resistance box to a value 100 ohms greater than the maximum value given by the parallel resistance curve for the cut-in temperature of their respective channels at the ambient temperatures recorded for the thermistor sensing elements.

(2) Switch on the a.c. and d.c. supplies and ensure that indicator lamps A and D are on and that lamps B and C are off.

(3) Decrease the decade resistance box for channel A through the equivalent value for the cut-in temperature of channel A and ensure that no change in the indication occurs.

(4) Further decrease the decade resistance in channel A until lamps A and B changeover (lamp A off, lamp B on).

(5) The resistance at which the changeover occurs must lie within the maximum and minimum value given by the parallel resistance curve for the cut-out temperature at the recorded ambient temperature.

(6) Increase the decade resistance in channel A until lamps A and B changeover (lamp A on, and lamp B off).

(7) The resistance at which this changeover occurs must lie within the maximum and minimum values given by the parallel resistance curve for the cut-in temperature of channel A at the recorded ambient temperature.

(8) Further increase the decade resistance in channel A until the previous setting of sub-para. (1) is reached.

(9) Repeat the tests given in sub-para. (3) to (8) using the decade resistance for channel B and the appropriate parallel resistance curves for the cut-in and cut-out temperature of the channel and the ambient temperature recorded for the sensing element of this channel.

Note . . .

The ambient temperature of each thermistor may be different. It is important that the temperature of the thermistor in each channel be ascertained before commencing a test.

21. If a controller, or one channel of a controller, fails the functional test given in para. 20 the cause may be due to either a faulty controller, a faulty temperature sensing element, or both. The controller may then be removed and tested in accordance with the Standard Serviceability Test given in Appendix A. The resistance of the thermistor may be measured using a Multimeter Type 1, or other suitable instrument provided that not more than 1 volt is applied to the thermistor. The reading obtained should be that of the thermistor at the ambient temperature as given in Chap. 7.

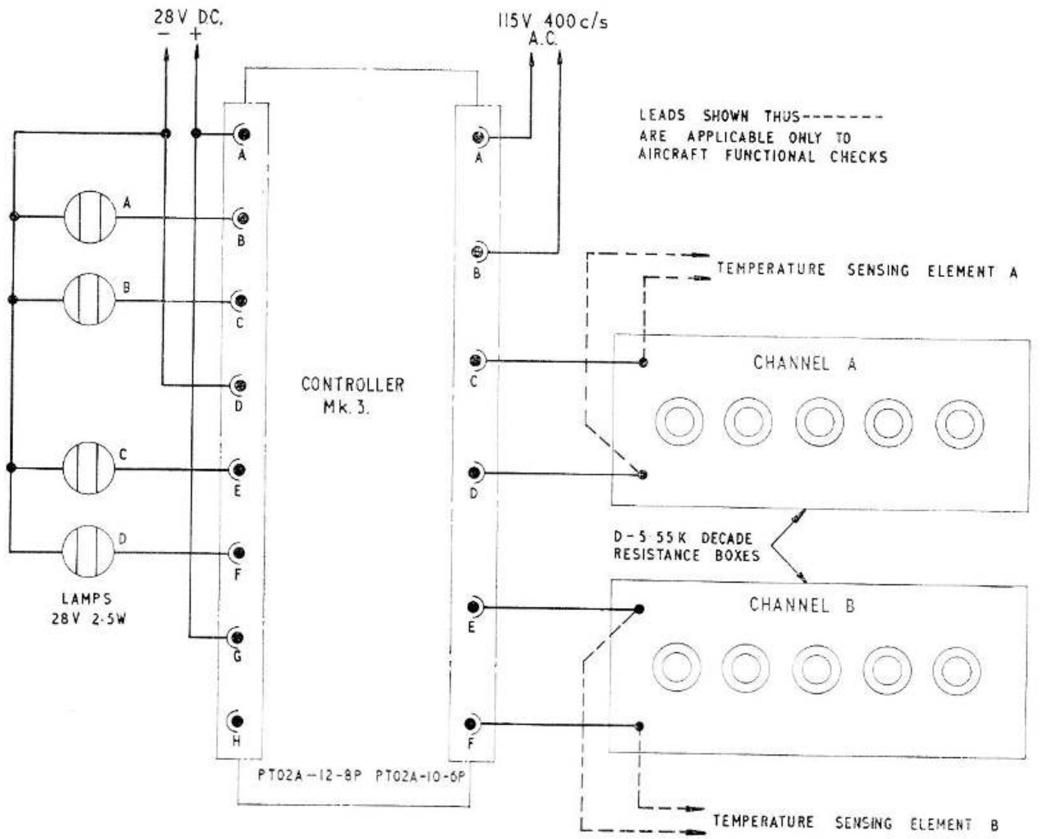


Fig. 6. Test circuit diagram

TABLE 2

List of components

Circuit reference	Description	Value
C1	Capacitor, tantalum Mallory	33μF 35V
C2	Capacitor, tantalum Mallory	150μF 6V
C3	Capacitor, tantalum Plessey	140μF 30V
C4	Capacitor, tantalum Mallory	68μF 15V
C5	Capacitor, tantalum Mallory	150μF 6V
C6	Capacitor, tantalum Mallory	33μF 35V
C7	Capacitor, tantalum Mallory	150μF 15V
C8	Capacitor, tantalum Plessey	4·7μF 35V
C9	Capacitor, tantalum Mallory	150μF 6V

TABLE 2—*continued*

List of components

Circuit reference	Description	Value
D1	Diode, silicon junction A.E.I. Type MS2H	
D2	Diode, silicon junction A.E.I. Type MS2H	
D3	Diode, silicon junction Mullard Type OA200	
D4	Diode, silicon junction Mullard Type OA200	
D5	Diode, silicon junction Mullard Type OA200	
D6	Diode, silicon junction Texas Inst. Type 1S 121	
D7	Diode, silicon junction Texas Inst. Type 1S121	
D8	Diode, silicon junction Mullard Type OA200	
PL1	Plug, Bendix-Thorn Type PTO2A—12—8P	
PL2	Plug, Bendix-Thorn Type PTO2A—10—6P	
	Resistor Bobbins for Ref. No. 5CZ/6903—	
R1	Differential bobbin, Channel A, NC0075/498/7	1440 ohms
R1	Differential bobbin, Channel B, NC0075/498/3	1680 ohms
R2	Range bobbin, Channel A, NC0075/498/6	960 ohms
R2	Range bobbin, Channel B, NC0075/498/1	730 ohms
	Resistor bobbins for Ref. No. 5CZ/6631 (pre mod. D1234)—	
R1	Differential bobbin, Channel A, NC0075/498/2	2155 ohms
R1	Differential bobbin, Channel B, NC0075/498/2	2155 ohms
R2	Range bobbin, Channel A, NC0075/498/1	730 ohms
R2	Range bobbin, Channel B, NC0075/498/1	730 ohms
	Resistor bobbins for Ref. No. 5CZ/6631 (post mod. D1234)—	
R1	Differential bobbin, Channel A, NC0075/498/3	1680 ohms
R1	Differential bobbin, Channel B, NC0075/498/3	1680 ohms
R2	Range bobbin, Channel A, NC0075/498/1	730 ohms
R2	Range bobbin, Channel B, NC0075/498/1	730 ohms
R3	Resistor Dubilier, Type BTT	8·2K ohms
R4	Resistor Dubilier, Type BTT	3·9K ohms
R5	Resistor Dubilier, Type BTT	3·3K ohms
R6	Resistor Dubilier, Type BTT	1·5K ohms
R7	Resistor Dubilier, Type BTT	18K ohms
R8	Resistor Dubilier, Type BTT	4·7K ohms
R9	Resistor Dubilier, Type BTT	1K ohms
R10	Resistor Dubilier, Type BTT	560 ohms
R11	Resistor Dubilier, Type BTT	220 ohms
R12	Resistor Dubilier, Type BTT	2·7K ohms
R13	Resistor Dubilier, Type BTT	2·2K ohms
R14	Resistor Dubilier, Type BTT	10K ohms
R15	Resistor Dubilier, Type BTT	2·2K ohms
RL	Relay, Clare P.O. Type F	
T1	Transformer Phortiphone	115V/1V & 24V
VT1	Transistor Mullard Type BCZ11	
VT2	Transistor Mullard Type BCZ11	
VT3	Transistor Mullard Type BCZ11	
VT4	Transistor Mullard Type OC702	

Appendix A

STANDARD SERVICEABILITY TEST
FOR
THERMAL CONTROLLERS, NAPIER MK. 3

Introduction

1. The following tests may be applied to ascertain the serviceability of a controller, or prior to its installation in an aircraft.

TEST EQUIPMENT

2. The following test equipment, or suitable equivalents, will be required:—

(1) Four 28V 2·5 watt filament lamps, Ref. No. 5L/9951286 in suitable M.E.S. Type lampholders (Type A warning lamps Ref. No. 5CX/1069 red, 5CX/1635 green).

(2) Two 0–11,110 ohm decade resistance boxes Ref. No. 10S/16239 or 10S/16238.

(3) A 28V d.c. supply and a 115V, 400 c/s a.c. supply.

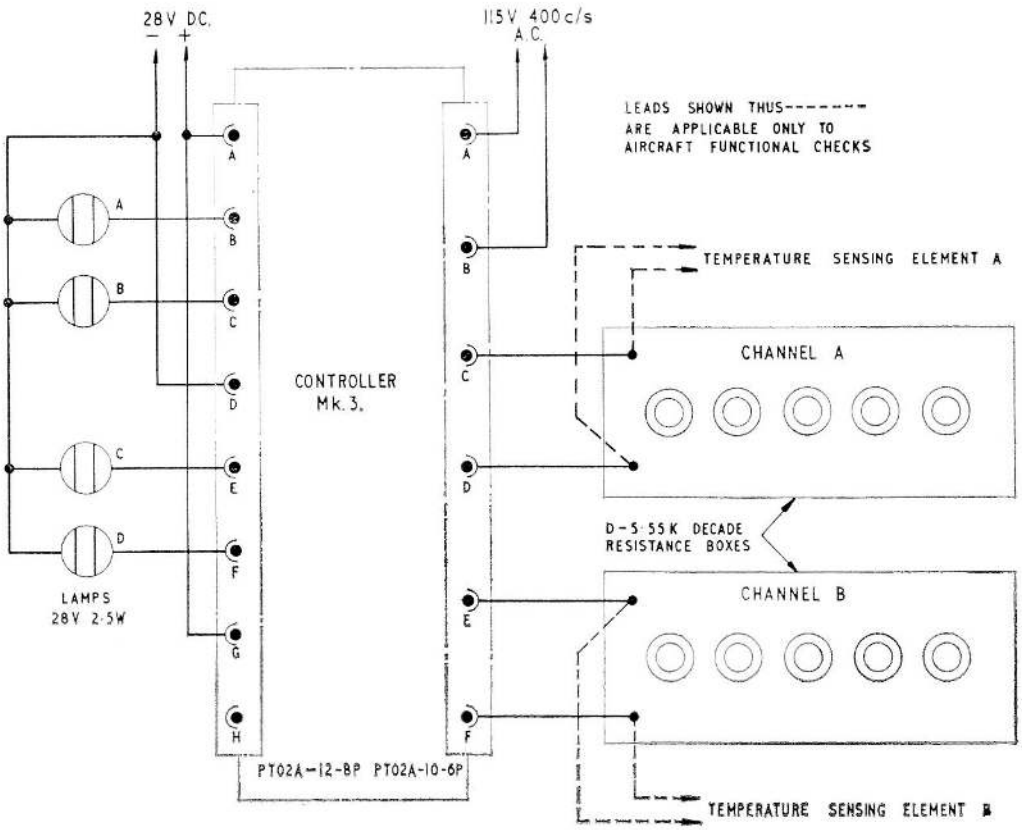


Fig. 1 Test circuit diagram

TEST PROCEDURE

3. (1) Connect the controller to a test circuit as shown in fig. 1 omitting the temperature sensing element connections.

(2) Set each decade resistance box to a value equivalent to the thermistor resistance at 10 deg. C. less than the controller cut-in temperature. The value may be determined by reference to Tables 1 and 2 (e.g. Controller Pt. No. 0075/506, cut-in temperature of Channel A from Table 1 is 40 deg. C. and the equivalent maximum resistance at 30 deg. C. from Table 2 is 3800 ohms).

(3) Switch on both the a.c. and d.c. supplies and ensure that the indicator lamps A and D are on and lamps B and C are off.

(4) Decrease the decade resistance in channel A through the equivalent resistance range for the channels cut-in temperature to the minimum as given in Table 2, no change in the indication of the lamps should occur (e.g. Controller Pt. No. 0075/506, cut-in temperature of channel A is 40 deg. C. and the equivalent minimum resistance 2184 ohms.)

(5) Further decrease the decade resistance in channel A until lamps A and B changeover (lamp A off and lamp B on). The resistance of the decade resistance at this point must be between the limits given in Table 3 for the channel cut-out temperature (e.g. Controller Pt. No. 0075/506 cut-out temperature, Channel A, 70 deg. C., equivalent resistance limits 990–936 ohms).

(6) Increase the decade resistance in channel A until lamps A and B change once more (lamp A on and lamp B off). The resistance of the decade resistor at this point must be between the limits given in Table 2 for the channel cut-in temperature (e.g. Controller Pt. No. 0075/506, cut-in temperature of Channel A is 40 deg. C. and the equivalent resistance limits at 40 deg. C. 2676–2184 ohms).

(7) Reset the decade resistance in channel A to a maximum as (2).

(8) Repeat the test procedure outlined in para. (2) to (7) for channel B, observing lamps C and D and checking the function of the channel within the limits for channel B which may be determined by reference to Tables 1, 2 and 3.

Insulation resistance test

4. The insulation resistance of the controller may be measured using a 500V insulation resistance tester, the reading obtained for any of the tests detailed below should be not less than 5 megohms.

◀ **Caution . . .**

The insulation resistance tester must not be connected to pins C, D, E and F of the 6-pole plug or damage to the unit will result. Test voltage on these pins is limited to 6V. ▶

(1) Test the insulation resistance between either pin A or pin B of 6-pole plug and the metal case.

(2) Test the insulation resistance between pins A, C, D, E and F of the 8-pole plug and the metal case.

(3) With the a.c. supply and decade resistance boxes connected to the 6-pole plug as shown in the test circuit diagram fig. 1, switch on the a.c. supply and decrease the resistance of both decade resistance boxes to the equivalent of 10 deg. C. greater than the cut-out temperature for their respective channels as obtained from Table 3. Test the insulation resistance between pins A and B, and between pins G and F, of the 8-pole plug.

(4) Increase the resistance of both decade resistance boxes to the equivalent of 10 deg. C. less than the cut-in temperature for their respective channels given in Table 2. Test the insulation resistance between pins A and C and between pins G and E of the 8-pole plug.

5. After completing all the tests disconnect the controller from the test circuit. Controllers which fail any of the above tests should be disposed of in accordance with current authorized procedure.

TABLE 1

Operating range and parallel resistance curve references

Part No.	Channel A				Channel B			
	Temperature range (Deg. C)		Resistance curve (Appendix)		Temperature range (Deg. C)		Resistance curve (Appendix)	
	Cut-out	Cut-in	Cut-out	Cut-in	Cut-out	Cut-in	Cut-out	Cut-in
NC.0075/506	70	40	3	2	80	40	4	2
NC.0075/508 (Pre Mod. D1234)	80	35	4	1	80	35	4	1
NC.0075/508 (Post Mod. D1234)	80	40	4	2	80	40	4	2

TABLE 2

Thermistor equivalent resistance values for thermal controller cut-in temperatures

Temp. °C	Resistance in Ohms		
	Max. (—3 deg. C)	Nominal	Min. (+3 deg. C)
25	4568	4136	3704
30	3800	3440	3080
35	3181	2880	2579
40	2676	2430	2184

TABLE 3

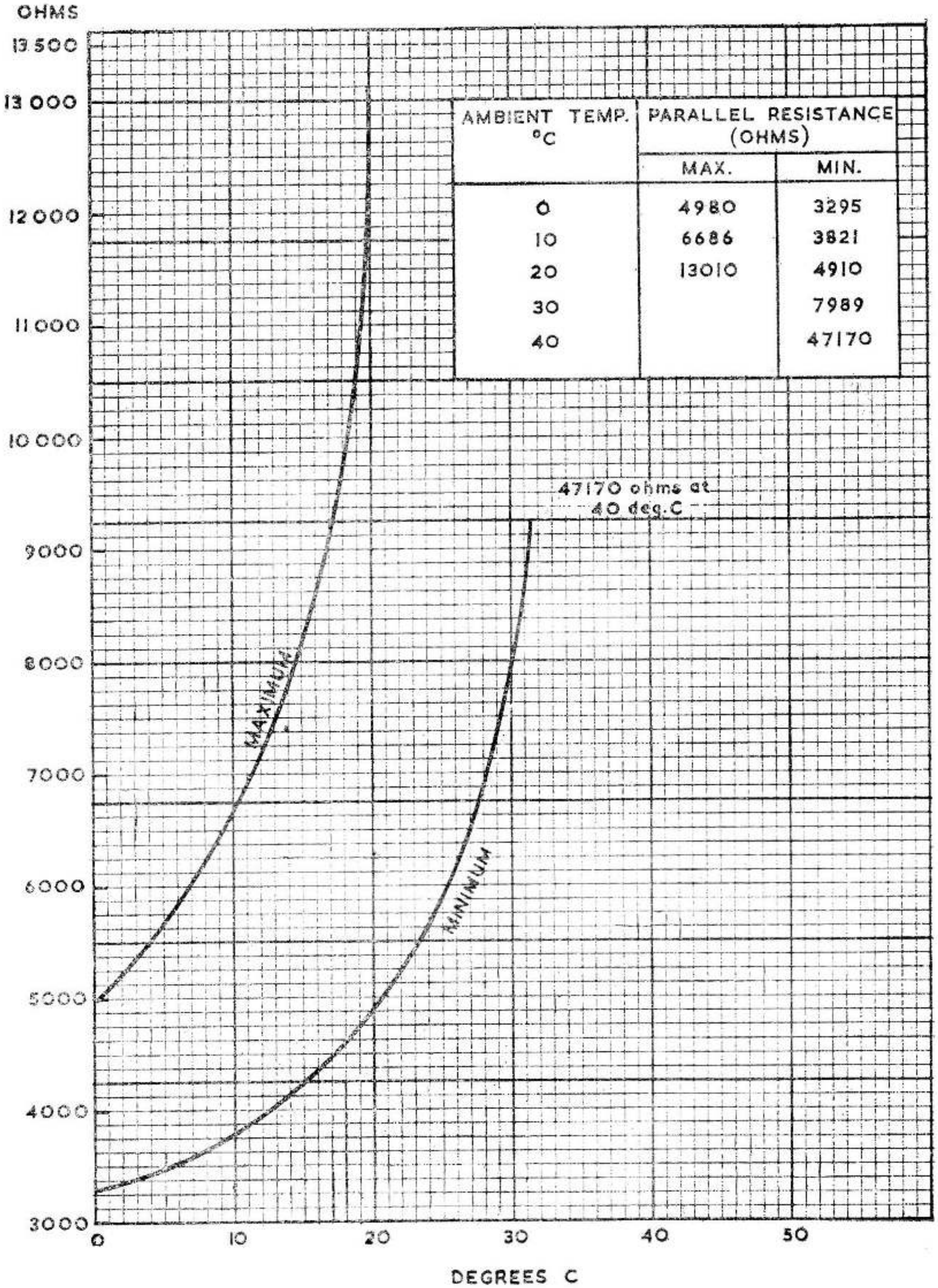
Thermistor equivalent resistance values for thermal controller cut-out temperatures

Temp. °C	Resistance in Ohms		
	Max. (—1 deg. C)	Nominal	Min. (+1 deg. C)
60	1328	1286	1250
70	990	963	936
80	749	730	711
90	580	566	552
100	454	443	432
110	359	351	343
120	288	282	276

Appendix 1

PARALLEL RESISTANCE VALUES, CUT-IN TEMPERATURE 35 deg. C.

1. The curve shown in the graph, fig. 1, gives the maximum and minimum values of the resistance which is connected in parallel with the thermistor sensing element when testing a thermal controller with a cut-in temperature of 35 deg. C. at the aircraft. The required resistance values are determined by first measuring the ambient surface temperature of the Spraymat at the location of the sensing element and then reading from the graph the resistance values, maximum and minimum, at this temperature (i.e. for an ambient surface temperature of 12 deg. C. the resistance to be connected in parallel with the sensing element to cause the controller to cut-in, test lamp A or D on, should be within the limits of 3950–7120 ohms).



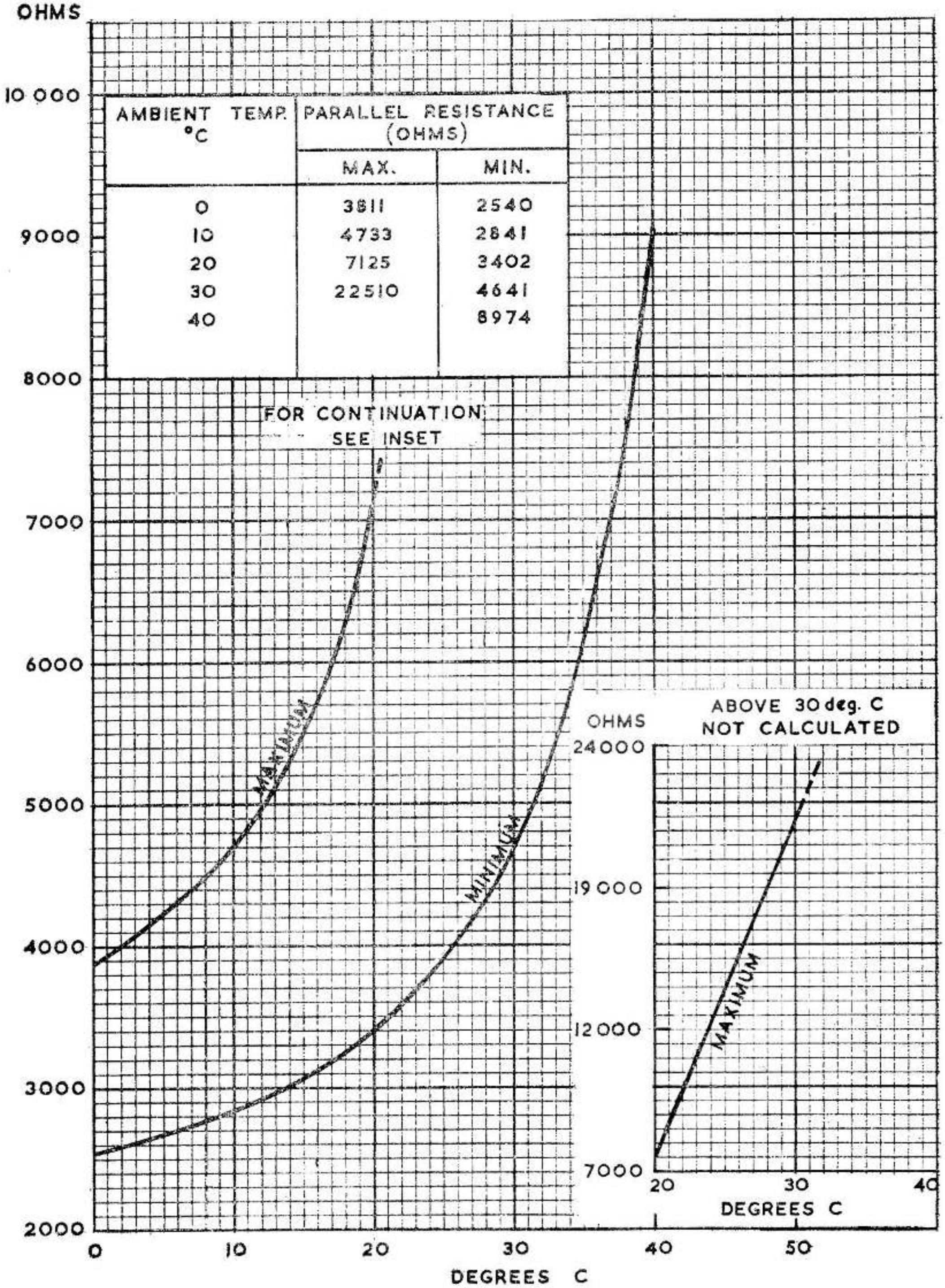
AMBIENT TEMP. °C	PARALLEL RESISTANCE (OHMS)	
	MAX.	MIN.
0	4980	3295
10	6686	3821
20	13010	4910
30		7989
40		47170

Fig. 1. Resistance/temperature curves

Appendix 2

PARALLEL RESISTANCE VALUES, CUT-IN TEMPERATURE 40 deg. C.

1. The curves shown in the graph, fig. 1 give the maximum and minimum values of the resistance which is connected in parallel with the thermistor sensing element when testing the cut-in operation of a thermal controller with a cut-in temperature of 40 deg. C. at the aircraft. The required resistance values are determined by first measuring the ambient surface temperature of the Spraymat at the location of the sensing element and then reading from the graph the resistance values, maximum and minimum at this temperature (i.e. for an ambient surface temperature of 15 deg. C. the resistance to be connected in parallel with the sensing element to cause the controller to cut-in, test lamp A or D on, should be within the limits of 3060–5500 ohms).



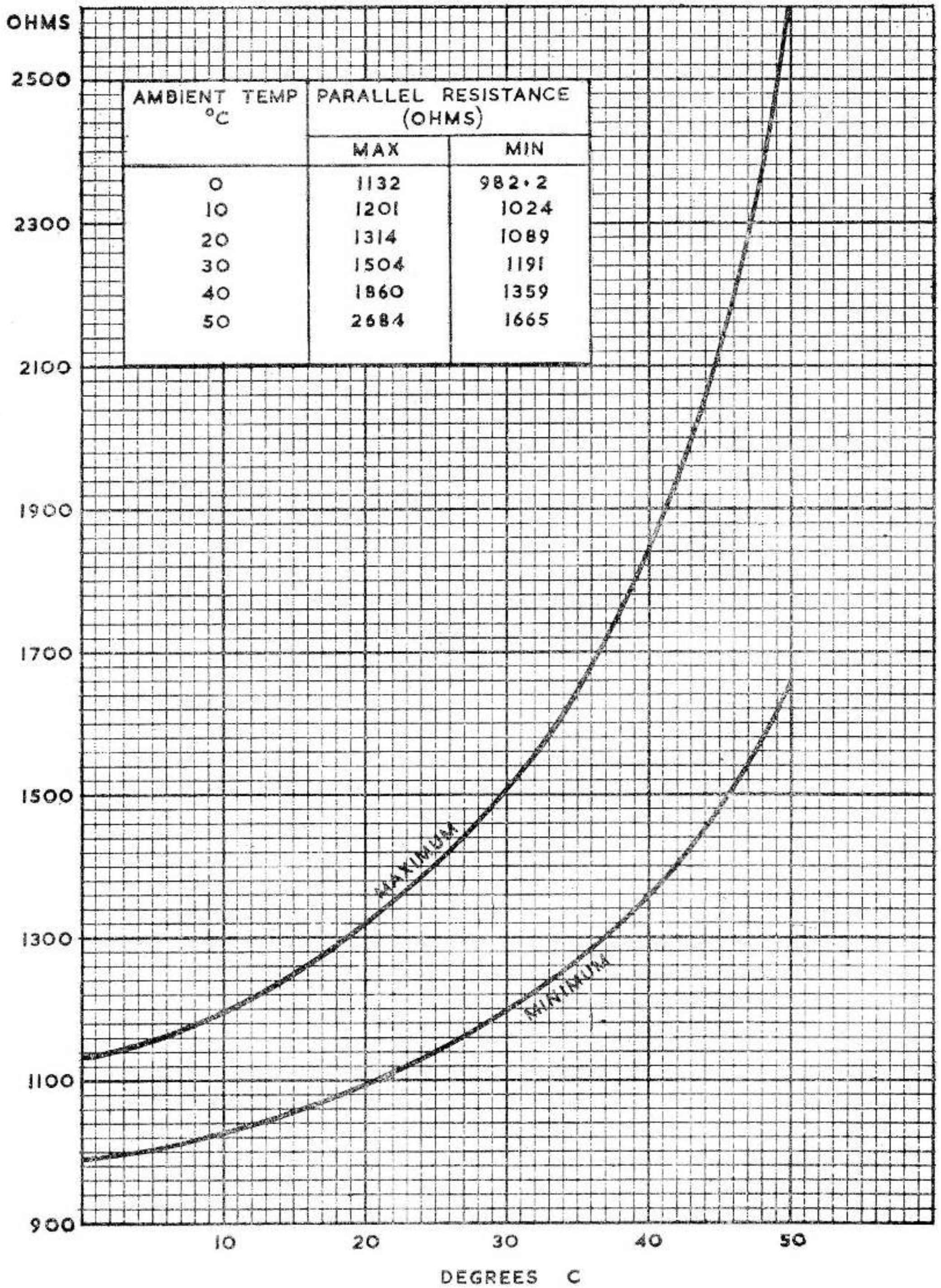
AMBIENT TEMP. °C	PARALLEL RESISTANCE (OHMS)	
	MAX.	MIN.
0	3811	2540
10	4733	2841
20	7125	3402
30	22510	4641
40		8974

Fig. 1. Resistance/temperature curves

Appendix 3

PARALLEL RESISTANCE VALUES, CUT-OUT TEMPERATURE 70 deg. C.

1. The curves shown in the graph, fig. 1, give the maximum and minimum values of the resistance which is connected in parallel with the thermistor sensing element when testing the cut-out operation of a thermal controller with a cut-out temperature of 70 deg. C. at the aircraft. The required resistance values are determined by first measuring the ambient surface temperature of the Spraymat at the location of the sensing element and then reading from the graph the resistance values, maximum and minimum at this temperature (i.e. for an ambient surface temperature of 10 deg. C. the required parallel resistance to be connected in parallel with the temperature sensing element to cause the controller to cut-out, test lamp B or C on, should be within the limits of 1024–1201 ohms).



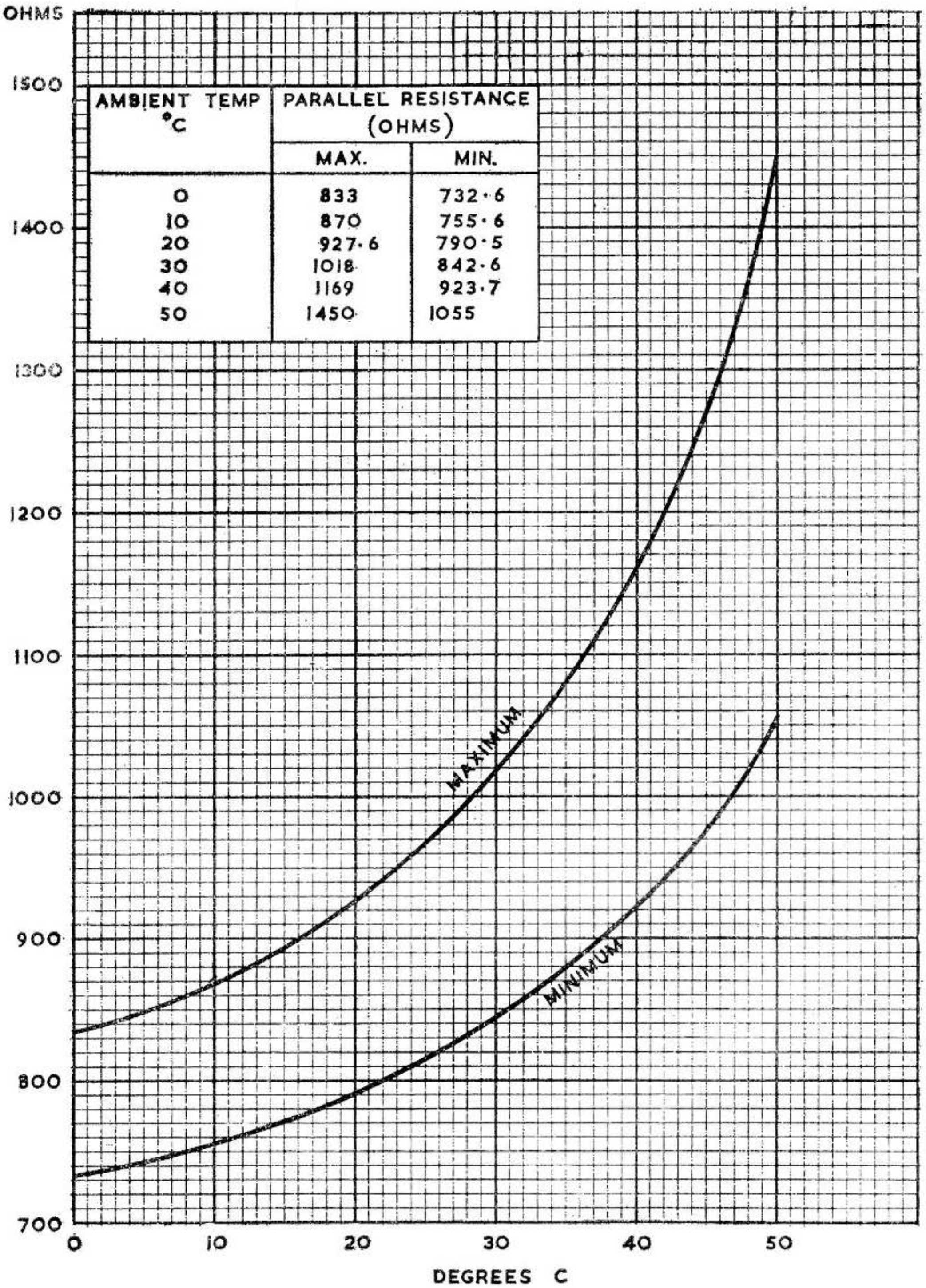
AMBIENT TEMP °C	PARALLEL RESISTANCE (OHMS)	
	MAX	MIN
0	1132	982·2
10	1201	1024
20	1314	1089
30	1504	1191
40	1860	1359
50	2684	1665

Fig. 1. Resistance/temperature curves

Appendix 4

PARALLEL RESISTANCE VALUES, CUT-OUT TEMPERATURE 80 deg. C.

1. The curves shown in the graph, fig. 1, give the maximum and minimum values of the resistance which is connected in parallel with the thermistor sensing element when testing the cut-out temperature of a thermal controller with a cut-out temperature of 80 deg. C. at the aircraft. The required resistance values are determined by first measuring the ambient surface temperature of the Spraymat at the location of the sensing element and then reading from the graph the resistance values, maximum and minimum, at this temperature (i.e. for an ambient surface temperature of 18 deg. C. the resistance to be connected in parallel with the sensing element to cause the controller to cut-out, test lamp B or C on, should be within the limits of 780–912 ohms).



AMBIENT TEMP °C	PARALLEL RESISTANCE (OHMS)	
	MAX.	MIN.
0	833	732·6
10	870	755·6
20	927·6	790·5
30	1018	842·6
40	1169	923·7
50	1450	1055

Fig. 1. Resistance/temperature curves

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