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A SOLAR CELL AND HEATER SYSTEM TO REDUCE THE TEMPERATURE VARIATION OF UNITS IN A SPACECRAFT

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SUMMARY

A simple semi-active system is described which will improve the thermal performance of some spacecraft employing an otherwise passive system of thermal control. This involves the use of a small array of solar cells to provide power to a resistor in a unit which may otherwise run too cold in some attitudes.

Departmental Reference: Space 221

CONTENTS

1 INTRODUCTION

A recurring problem with spacecraft which employ a passive means of thermal control, is that when all possible combinations of solar aspect and orbit eclipse are considered, it can be difficult to ensure that every item on board will remain comfortably within its acceptable temperature range.

Taking the specific case of a small spinning spacecraft, it is usually a straightforward matter to choose thermal control surfaces which will give a satisfactory temperature distribution in the structure when the spacecraft is side to the Sun: in this attitude the spin of the spacecraft helps to distribute the incident heat flux, and temperature gradients are consequently small. In the end-on cases, however, when the Sun shines along the spin axis, the spin is of no assistance in distributing the heat, and considerable temperature gradients can develop along the direction of the spin axis; the temperature difference between units at the top and bottom of the structure can be 60 C° or more. The absolute temperatures at which these units operate can be changed by varying the thermal control surfaces on the spacecraft's skin, but little can be done by this means to alter the temperature difference; consequently, if a choice of surfaces is made which ensures that the hot unit is well within its maximum operating temperature, then it is likely that the cold unit will come dangerously close to its minimum operating temperature. Since the tape recorder is often mounted near the base of a spacecraft to minimise vibration effects during launch, and since the low temperature performance of the tape recorder is usually poorer than that of most other items in the spacecraft (a minimum operating temperature of about -5°C being typical), it is a unit which regularly threatens to run too cold when the top of the spacecraft faces the Sun. It is desirable to find some way out of this dilemma without resorting to a fully active thermal control system with it accompanying complexity, expense, and possible unreliability. This Report describes a simple semi-active system which may be used to overcome this problem.

2 DESCRIPTION OF SYSTEM

The system proposed is very simple. A small array of solar cells is fixed to a surface of the spacecraft which is fully illuminated when the critical unit is at its minimum temperature. The power from the array is fed directly into the unit and is dissipated in a resistor. This added power dissipation increases the temperature of the unit by an amount controlled by the rate at which heat can be radiated and conducted away to the rest of the spacecraft: the poorer the thermal contact with the rest of the spacecraft, the greater is the temperature rise produced by this extra power. It will be seen that such a system is substantially passive in that no switching or electronic control is necessarily employed, yet the power input to the resistor varies automatically with changes in solar aspect in the desired way.

Fig.1 shows an example of how the system could be used in practice. In the structure shown, a tape recorder is mounted near the bottom and, with the Sun shining on the top end, there would be a tendency for this unit to run cold. With a 6 × 7 panel of 2 × 2 cm solar cells mounted on the top surface as shown, a dissipation of up to 1 or 2 watts could be obtained in a resistor mounted inside the recorder; this array size is mentioned since it corresponds to a standard module on the forthcoming Black Arrow series of spacecraft.

Efforts are usually made to maximise heat transfer between one part of a spacecraft and another by covering all internal surfaces with high emittance paint and assuring good conduction paths in the structure; this keeps thermal gradients to a minimum. It is envisaged that this philosophy would in general be applied to this spacecraft; however, to obtain the best effect from the heat dissipated in the resistor, it would be necessary to insulate the recorder partially from the rest of the structure. This would be done conductively by insulating the unit at its mounting points, and radiatively by wrapping it in aluminised Mylar.

How effective this insulation has to be can be investigated by adding further detail to the example. Suppose the tape recorder to be the type used in the UK3 spacecraft, this being in external shape a cylinder about $3\frac{1}{2}$ inches long and 7 inches in diameter. The effects of internal dissipation can be examined by considering the recorder to be radiating, in vacuum, in an isothermal enclosure. The internal dissipation would cause the recorder temperature to rise relative to the temperature of the enclosure, and in steady state this condition would be described by the equation

$$I = A e \sigma (T_r^4 - T_e^4) \qquad (1)$$

where I is the internal dissipation in the recorder

A is the external surface area of the recorder

e is the effective emittance between the recorder and the enclosure wall

σ is the Stefan-Boltzmann constant

T_r is the temperature of the recorder

and T_e is the temperature of the enclosure.

Re-writing equation (1),

$$T_r = \left\{ \frac{I}{A\,e\,\sigma} + T_e^4 \right\}^{\frac{1}{4}} \quad . \tag{2}$$

Putting $A = 1000$ cm^2 for the tape recorder, and substituting the numerical value for σ, a plot of ΔT $(= T_r - T_e)$ versus (I/e) can be obtained and this is shown in Fig.2. From the graph it will be seen that if the tape recorder were covered with a high emittance paint, and the additional dissipation were about 1 watt, the consequent temperature rise would be only about 2 C^o. Such a rise would be inadequate to cope with any overcooling problem, and to increase ΔT to a useful level (say 10 C^o or more), the value of e would have to be decreased to 0.2 or less. By wrapping the unit in aluminised Mylar, it is in principle possible to reduce the effective emittance to about 0.01 or 0.02; but in fact this would be difficult to achieve due to heat leakage near plugs, and the difficulty of making the conductive insulation sufficiently effective. Combining conduction and radiation, the minimum practicable heat loss would probably be equivalent to having an emittance of about 0.1, and in this case a temperature rise of about 20 C^o should be possible with a 1 watt dissipation in the resistor.

The above outlines the broad principle of the system, but there are a number of details which have to be considered in each practical application. These are considered below:-

(a) Care has to be taken to match the dissipating resistor to the characteristics of the solar cell array. Fig.3 shows the variation with temperature of the V-I characteristic for an irradiated patch of 42 series connected 2 × 2 cm solar cells (a standard Black Arrow module). In a minimum sunlight orbit the temperature of the solar cell array may be quite low when the spacecraft first comes out of the Earth's shadow, and would have to rise some 50 to 100 C^o before reaching its steady illuminated temperature. This feature can be used to reduce the difference in mean power dissipation in the resistor between a minimum and maximum sunlight orbit. Fig.3 shows typical working points of the array, and it will be seen that the mean dissipation over the whole orbit need not vary very greatly despite the different conditions. Also in this context it should be noted from Fig.4 that units at the unilluminated end of a spacecraft run at much the same temperature whether the orbit is in minimum or maximum sunlight; this is because heat input from the Earth to that part of the spacecraft in a minimum sunlight orbit is substantially higher than in a maximum sunlight orbit, and this helps to counter the effect of the reducted mean solar flux.

(b) It has been suggested earlier that an effective emittance of about 0.1 is a practicable minimum for the unit being controlled. This is a somewhat arbitrary figure and could be improved upon in some circumstances. However, such an improvement might not be an advantage since a very high value of (I/e) would be obtained, and this could cause overheating problems. In any case, such values are likely to be unstable due to the variability of very low emittance surfaces (a change in e from 0.02 to 0.03 could alter ΔT by 30 C^{o}). To avoid such uncertainties, it is advisable to limit the insulation so that $e \nless 0.1$; this could be ensured by having an area of suitable dimensions on the unit which is free of all aluminised Mylar and is painted black.

A further matter which must be considered is the effect of the internal dissipation of the unit without the added resistor. Too much insulation could cause the unit to overheat in another operational attitude.

(c) If desired, the system may be made active by putting a thermal switch in series with the resistor. Suitably small switches are available commercially. With such a system very low values of e could be employed without fear of overheating, and an added flexibility is provided which could be valuable in some applications.

(d) Electrical compatibility problems would have to be examined, especially with respect to the unit being controlled. LR or CR filtering could be included if necessary, but noise frequencies would be very low and would be unlikely to cause trouble.

3 COST AND WEIGHT

The predominant cost would be in the solar cell array. A fully mounted and connected array of solar cells of the size described here would cost about £200; such a cost assumes that the array could be made on an already available production jig. The approximate weight of the various components in the system is given below.

Solar cell array (depending on mounting)	35 to 100 gm
Wire-wound resistor	5 gm
Thermostat switches (optional)	1 gm each
Mounting, wiring, etc.	20 gm
Total, say, between	60 and 125 gm

4 COMMENTS

The use of electrical power to assist in the thermal control of units in a spacecraft is not new - it being employed extensively, for example, in the OGO spacecraft. The present system, however, has the advantage of not making a demand on the main power supply in the spacecraft, this being particularly valuable on small spacecraft. Also, since the array can be positioned to suit the specific task of controlling the temperature of one unit, its output changes suitably as the solar aspect changes, and no switching is necessary; the system therefore is still virtually passive.

Because of its versatility, and low weight and cost, the system can easily be incorporated into a spacecraft at a fairly late stage in its development, and could be useful to deal with the problem of a unit which does not achieve its expected thermal performance. Early realisation that it may be required is of course desirable, especially as effective conductive insulation might involve a major modification of the unit near the attachment points.

It is also likely to be valuable, in some cases, to consider the inclusion of this system in a spacecraft from the very inception of the design. With extra heating in critical areas, it may be possible to employ cheap and stable thermal control surfaces which otherwise would have to be abandoned solely because one unit threatened to run cold. In such cases the extra cost of this system is likely to be small compared with the saving in having cheap finishes on the main surfaces.

It is envisaged that this system will find application in some of the Black Arrow spacecraft.

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Fig.I

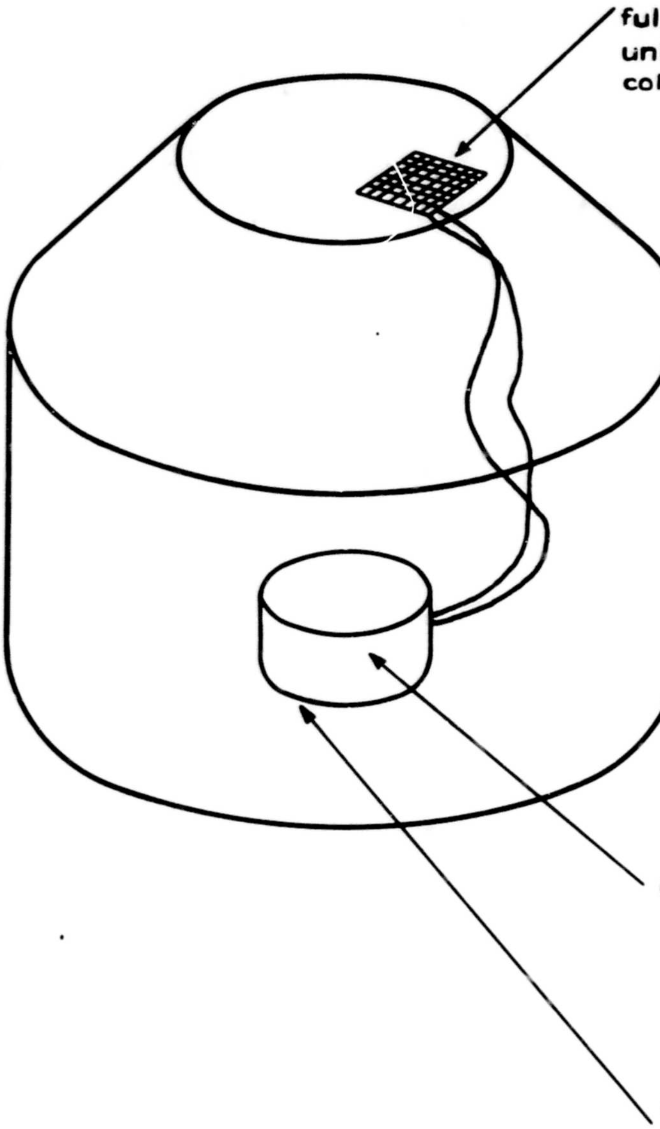

Fig.I Typical application of system

Fig. 2

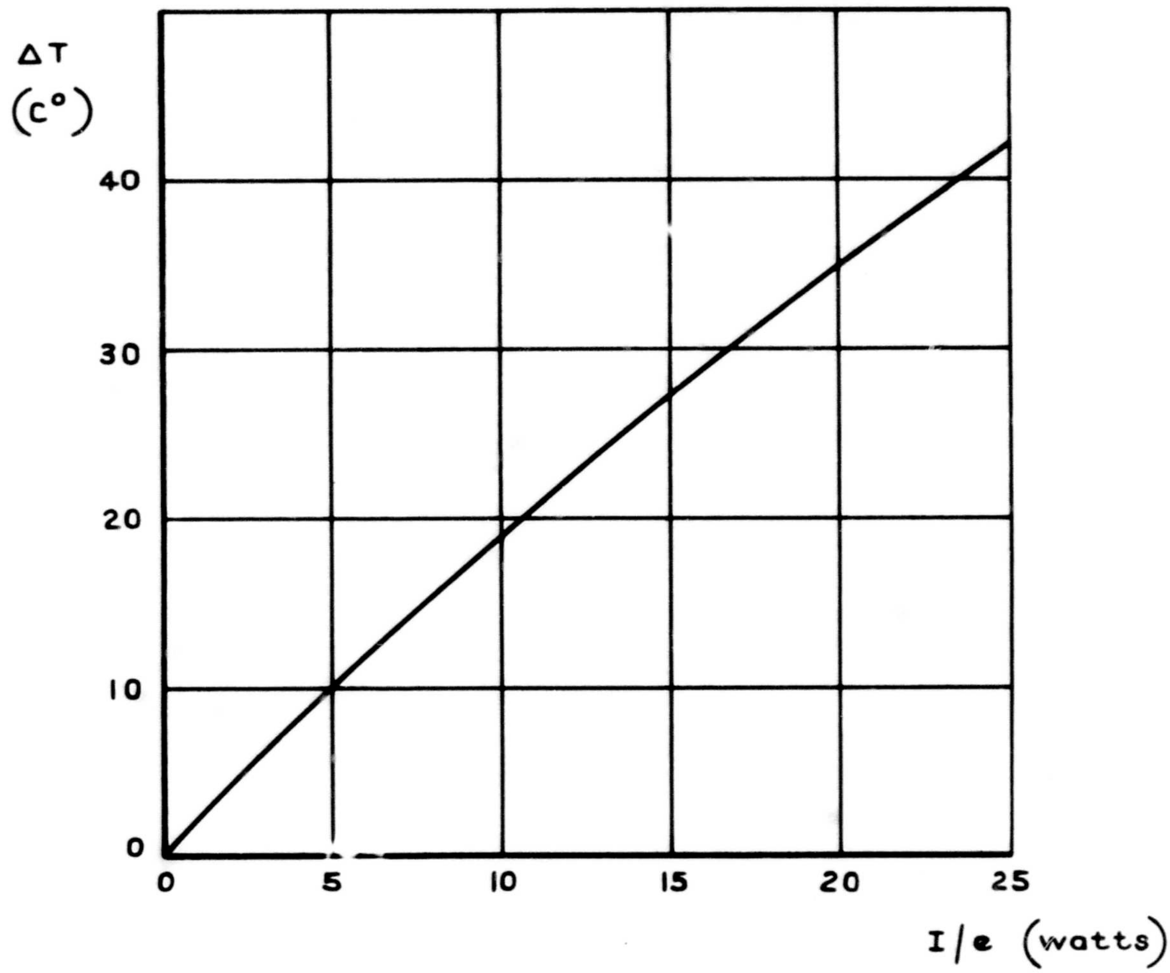

Fig. 2 Variation of temperature rise of unit with ratio of dissipation to emittance

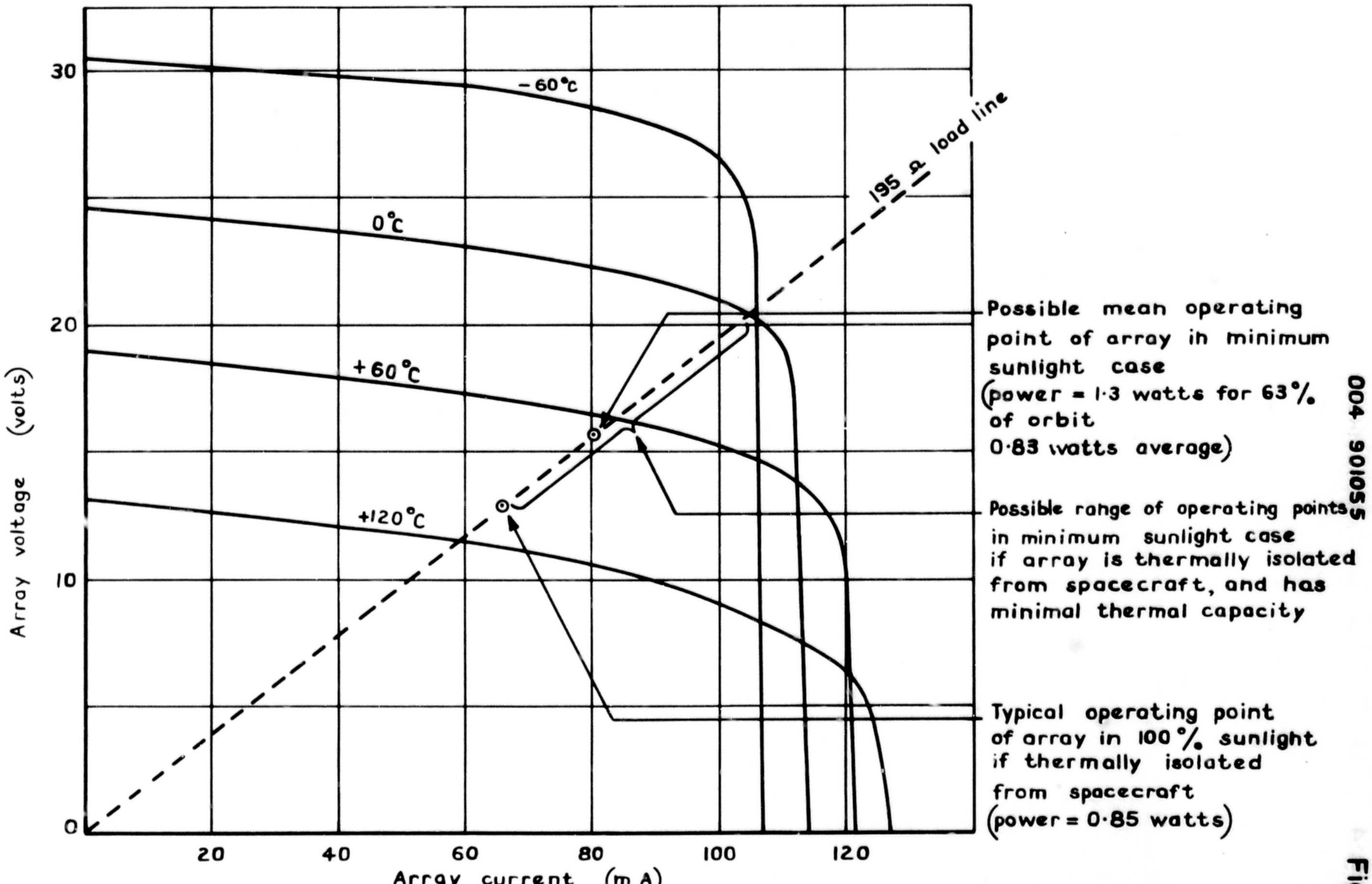

Fig. 3 V-I Characteristics of solar cell array showing operating points under load

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Fig. 3

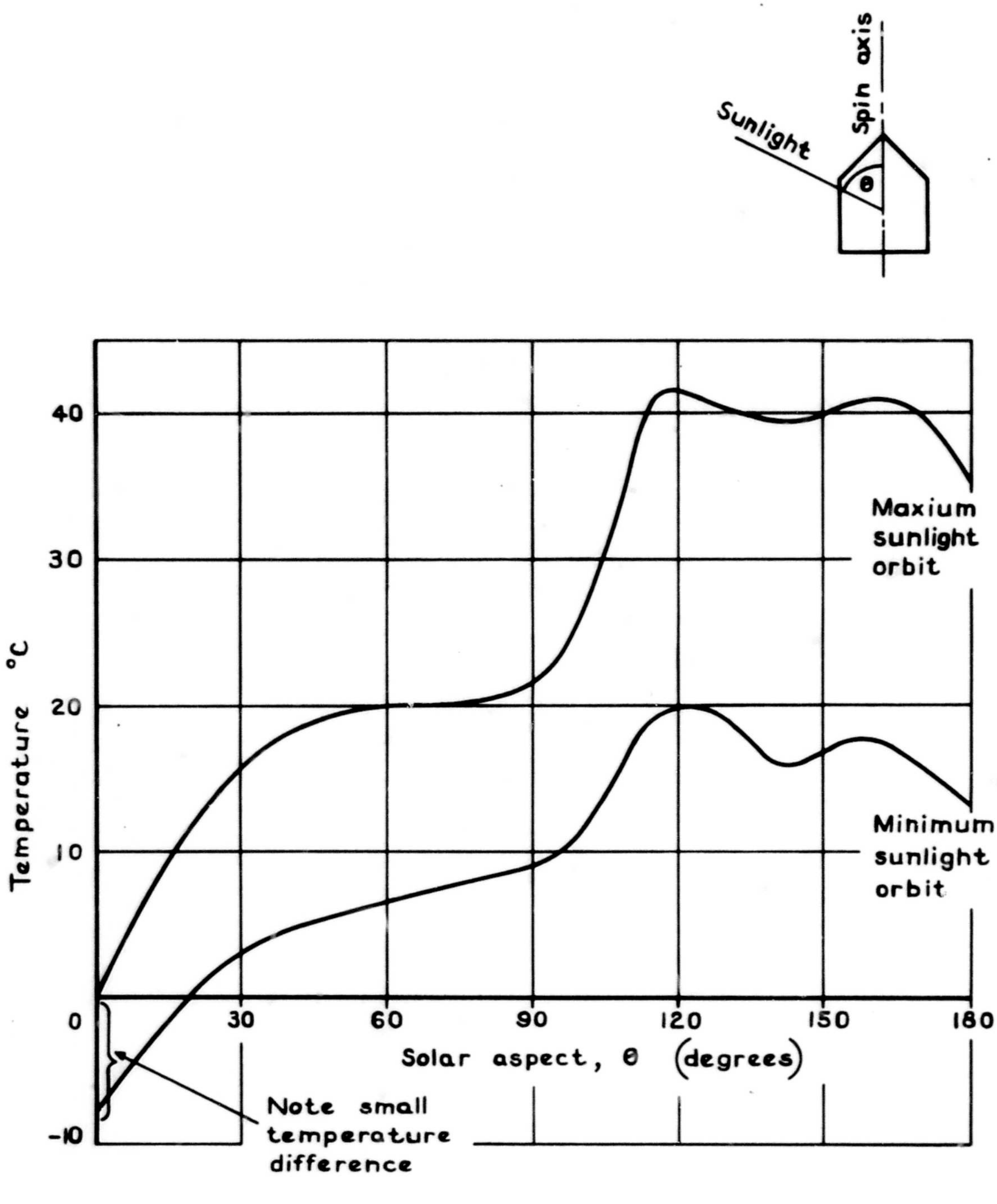

Fig.4 Predicted temperature variation of tape recorder on UK3 spacecraft