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THERMAL CONTROL CHARACTERISTICS OF
A DIFFUSE BLADED, SPECULAR BASE LOUVER SYSTEM

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Movable shutters or louvers are an active means used for spacecraft thermal control. A louver system consisting of diffuse, low-emissivity, movable, parallel blades and a specular, high-emissivity base is analyzed. The analysis considers the solar radiosity to be different for distinct basic areas on the diffuse blades. These basic areas are due to only partial solar impingement of the blades. From the analysis all applicable heat transfer characteristics are derived for all possible solar angles and blade opening angles. A comparison of the results of this anlaysis with that of the presently used specular blade diffuse base louver system shows that this new configuration has the capability of dissipating eight times as much heat as the present system in full sunlight for one particular blade and solar angle[1]. The minimum blade temperature will be about 200°R less for the diffuse bladed system because of the elimination of the multiple specular reflections of the sun's energy by a specular blade. The results are presented graphically for a base temperature of 530°R(21°C).

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(1) Buskirk, D. L., "Thermal Characteristics of Specular-Diffuse Temperature Control Systems in a Solar Space Environment," Ph.D. Thesis, October, 1967, West Virginia University, Morgantown, West Virginia.

ASSUMPTIONS

In order to facilitate the mathematical analysis of the diffuse bladed specular base louver system the following assumptions are made:

1) The blades form an infinite array so that edge effects may be neglected.
2) Kirchoffs identity applies in both the solar and infrared wavelength regions so that $\alpha_s = 1 - \rho_s$ and $\rho_t = 1 - \alpha_t = 1 - \varepsilon_t$.
3) The radiosity of the blades and base are uniform within defined regions of illumination.
4) The internal conductance of the blades and base is infinite so that they are isothermal.
5) There is no conduction or convection between surfaces.
6) The blades are diffuse.
7) The base is diffuse emitting but specular reflecting.

METHOD OF CALCULATION

The incident solar radiation may illuminate a louver section directly, after specular reflection, and after diffuse reflection as illustrated in Figure 1. The amount of energy which strikes a surface is determined by geometry. For example, in Figure 1, the points a, b, c, d, f and g are easily located as a function of and the intercept of the suns rays through these points with the y axis is found from simple algebra. The images of points a, c, f, and g are denoted by primes while the images of surfaces 1, 1', 1", and 2 are denoted by the addition of 3. The direct illumination of surface number one is caused by a reflection from surface number three. The illumination band will be from point c to f (A_1',) and the amount of energy striking area A_1', is:

$$G_{A'} = \ _3S(Y_a - Y_d) \sin|\phi| \quad , \tag{1}$$

the amount of energy striking area A_2 directly is:

$$G_{A_2} = S(Y_d - Y_g) \sin|\phi| , \tag{2}$$

and the amount of energy striking surface A_3 is:

$$G_{A_3} = S(Y_a - Y_d) \sin|\phi| \tag{3}$$

where: G = the irradiation of a surface, watts (BTU/hr)

ρ = the reflectance of a surface, dimensionless

Y = the position on the ordinate, meter (ft)

S = the solar thermal radiation constant, 1393.4 W/M^2, (442 $BTU/hr\text{-}ft^2$)

ϕ = the solar polar angle, degrees

Now that the direct solar illumination of the surfaces is known a system of equations may be written for the radiosities of the surfaces: Again with reference to Figure 1: the radiosity of surface A_1 (b to g) caused by solar radiation is

$$A_1 J_{s1} = \rho_{s1} \Big[G_1 + A_1 F_{(1-1)T_s} J_{s1} + A_2 F_{(2-1)T_s} J_{s2} + A_{1'} F_{(1'-1)T_s} J_{s1'} + A_{1''} F_{(1''-1)T_s} J_{s1''} \Big] \qquad (4)$$

for A_2 (d to g)

$$A_2 J_{s2} = \rho_{s2} \Big[G_2 + A_1 F_{(1-2)T_s} J_{s1} + A_2 F_{(2-2)T_s} J_{s2} + A_{1'} F_{(1'-2)T_s} J_{s1'} + A_{1''} F_{(1''-2)T_s} J_{s1''} \Big] \qquad (5)$$

for $A_{1'}$, (c to f)

$$A_{1'} J_{s1'} = \rho_{s1'} \Big[G_{1'} + A_1 F_{(1-1')T_s} J_{s1} + A_2 F_{(2-1')T_s} J_{s2} + A_{1'} F_{(1'-1')T_s} J_{s1'} + A_{1''} F_{(1''-1')T_s} J_{s1''} \Big] \qquad (6)$$

for $A_{1''}$ (f to a)

$$A_{1''} J_{s1''} = \rho_{s1''} \Big[G_{1''} + A_1 F_{(1-1'')T_s} J_{s1} + A_2 F_{(2-1'')T_s} J_{s2} + A_{1'} F_{(1'-1'')T_s} J_{s1'} + A_{1''} F_{(1''-1'')T_s} J_{s1''} \Big] \qquad (7)$$

where: $F_{(i-j)T_s}$ = the total imaged view factor from surface i to j, dimensionless

J_s = the radiosity of a surface caused by solar illumination both direct and indirect, W/M^2 ($BTU/hr\text{-}ft^2$)

A = the area of the surface, M^2 (ft^2)

The areas, direct illuminations, and view factors are known functions of geometry and material properties. Equations 4, 5, 6 and 7 may be solved for the solar radiosities of each area. Once the radiosities are known, the amount of solar radiation absorbed by each area can be calculated from the following relations:

$$Q_{si} = \frac{\alpha_{si} J_{si}}{\rho_{si}}$$

$$Q_{s3} = \alpha_{s3}\Big[G_{A3} + A_1 F_{(1-3)TS} J_{s1} + A_2 F_{(2-3)TS} J_{s2} + A_1' F_{(1'-3)TS} J_{s1'} + A_1'' F_{(1''-3)TS} J_{s1''}\Big] \quad (8)$$

where Q_{si} is the solar radiation absorbed by area i, W (BTU/Hr)

The terrestrial emittance characteristic of the system can be determined by solving the heat balance equations for each surface in the system:

for blade 1*,

$$A_1 J_{t1} = \rho_{t1}\Big[\varepsilon_{t3}\sigma T_3^4 A_3 F_{(3-1)T_t} + A_1 F_{(1-1)T_t} J_{t1} + A_2 F_{(2-1)T_t} J_{t2}\Big] + A_1 \sigma \varepsilon_{t1} T_1^4 \quad (9)$$

for blade 2,

$$A_2 J_{t2} = \rho_{t2}\Big[\varepsilon_{t3}\sigma T_3^4 A_3 F_{(3-2)T_t} + A_1 F_{(1-2)T_t} J_{t1} + A_2 F_{(2-2)T_t} J_{t2} + A_2 \sigma \varepsilon_{t1} T_1^4 \quad (10)$$

Since the blades are isothermal $T_1 = T_2$ and because the blades are not a source or sink for heat, the energy emitted by them is equal to the energy absorbed.

* Note the blade areas are equal $A_1 = A_2 = \overline{ba}$ (Figure 1)

$$A_1 \epsilon_{t_1} \sigma T_1^4 +$$

$$A_2 \epsilon_{t_2} \sigma T_2^4 = \alpha_{t_1}\left[A_1 F_{(1-1)T_t} J_{t_1} + A_2 F_{(2-1)T_t} J_{t_2} + A_3 \epsilon_{t_3} \sigma T_3^4 F_{(3-1)T_t}\right]$$

$$+\alpha_{t_2}\left[A_1 F_{(1-2)T_t} J_{t_1} + A_2 F_{(2-2)T_t} J_{t_2} + A_3 \epsilon_{t_3} \sigma T_3^4 F_{(3-2)T_t}\right]$$

$$+ Q_{SB1} + Q_{SB2} \tag{11}$$

where

$$Q_{SB1} = Q_{S1} + Q_{S1}' + Q_{S1}''$$

The equations (9, 10 and 11) may be solved for J_{t1}, J_{t2}, and T_1.

The amount of emitted energy absorbed by each surface may then be calculated by the following relations.

$$Q_{t_1} = \frac{\alpha_{t_1}}{\rho_{t_1}}\left[J_{t_1} - E_{t_1}\right] \tag{12}$$

$$Q_{t_2} = \frac{\alpha_{t_2}}{\rho_{t_2}}\left[J_{t_2} - E_{t_2}\right] \tag{13}$$

$$Q_{t_3} = \alpha_{t_3}\left[A_1 F_{(1-3)T_t} J_{t_1} + A_2 F_{(2-3)T_t} J_{t_2}\right] \tag{14}$$

the net energy transfer at the base is,

$$Q_{NET\,3} = A_3 \epsilon_{t_3} \sigma T_3^4 - \left(Q_{S3} + Q_{t_3}\right) \tag{15}$$

RESULTS

The preceeding equations were solved by digital means for a louver system having blade properties $_s = 0.80$, $_t = 0.10$, and base properties $_s = 0.90$, $_t = 0.85$. The base temperature was assumed to be constant at 530°R (21°C). The chosen base temperature is typical of a spacecraft requirement. The blade and base properties are representative of a combination which is obtainable. The maximum calculated blade temperature is 840°R (193°C). The system also has the ability to reject heat in full sunlight ($\Phi = 0$) at 530°R. This compared favorably to the specular blade, diffuse base system which has maximum blade temperatures of 1040°R (304°C) and a very low heat dissipation capacity in full sunlight.

Notice that the blade temperature increased for solar angles from $\Phi = 0°$ to $\Phi = 30°$ while the heat rejection capacity decreased in the same limit. However, due to the geometry of the system, the heat rejection capacity begins to increase for any solar angle greater than 30°, while the blade temperature decreases.

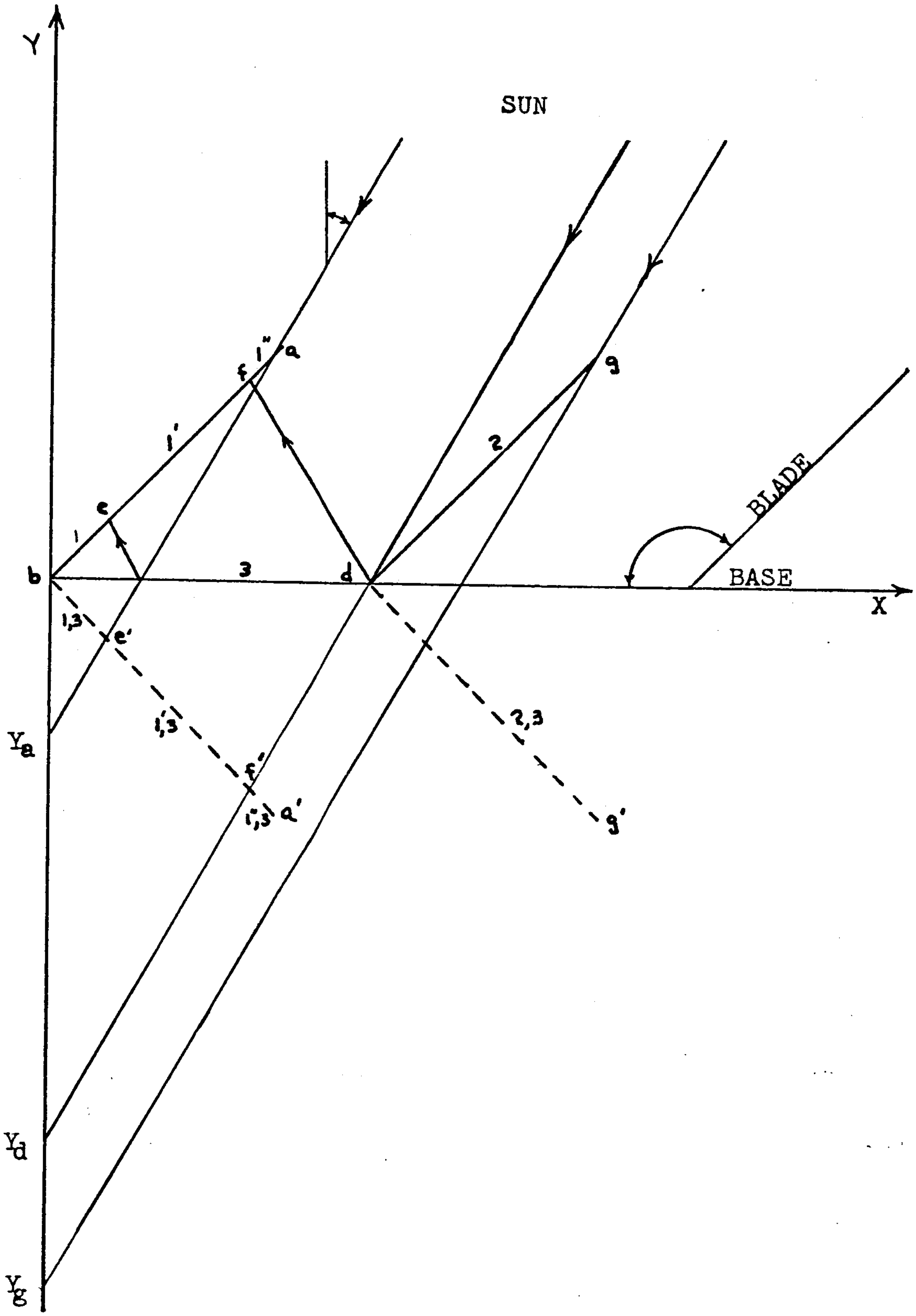

FIGURE 1 SCHEMATIC DIAGRAM FOR ILLUMINATION OF LOUVERS

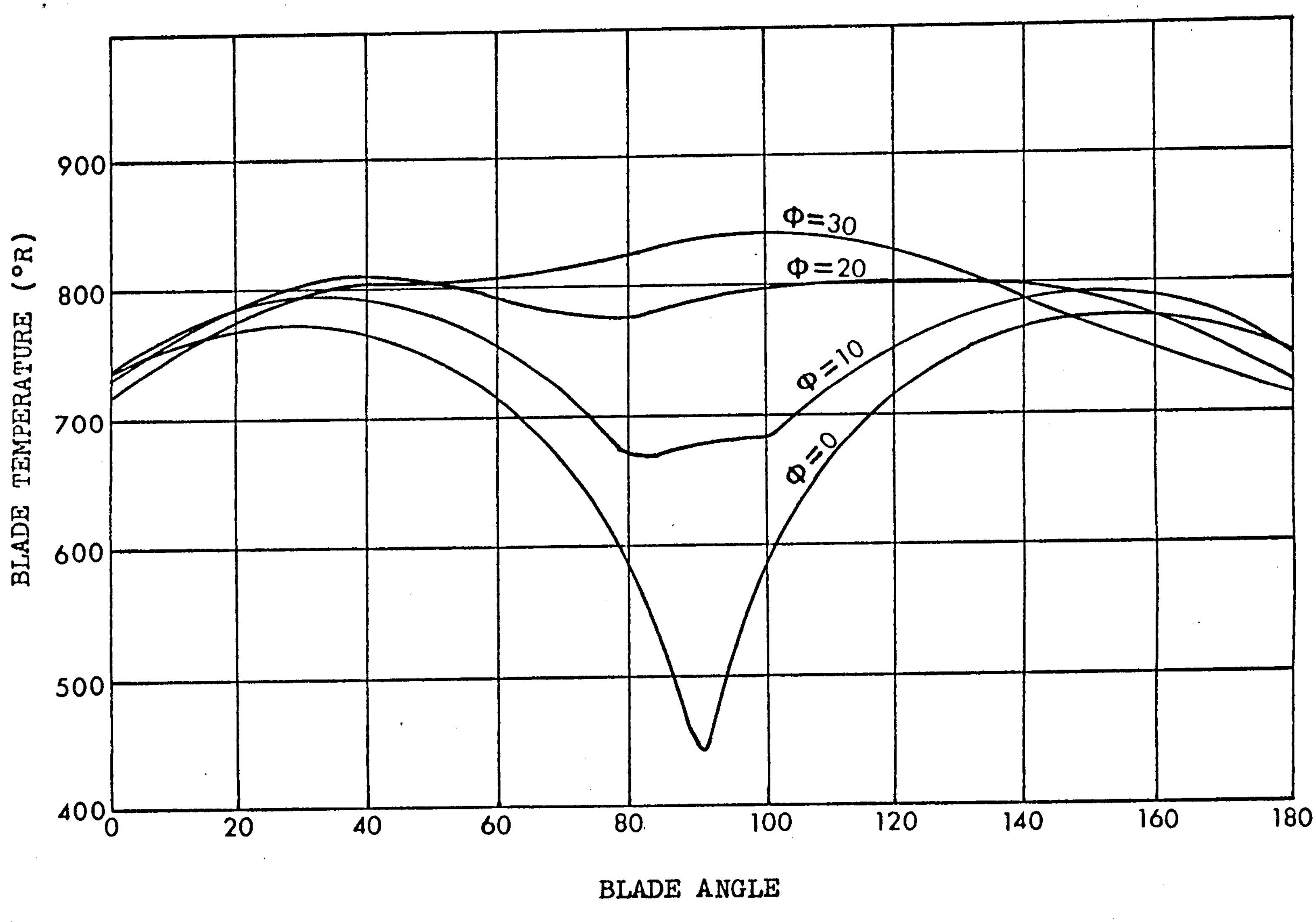

FIGURE 2 TEMPERATURE OF LOUVER BLADES

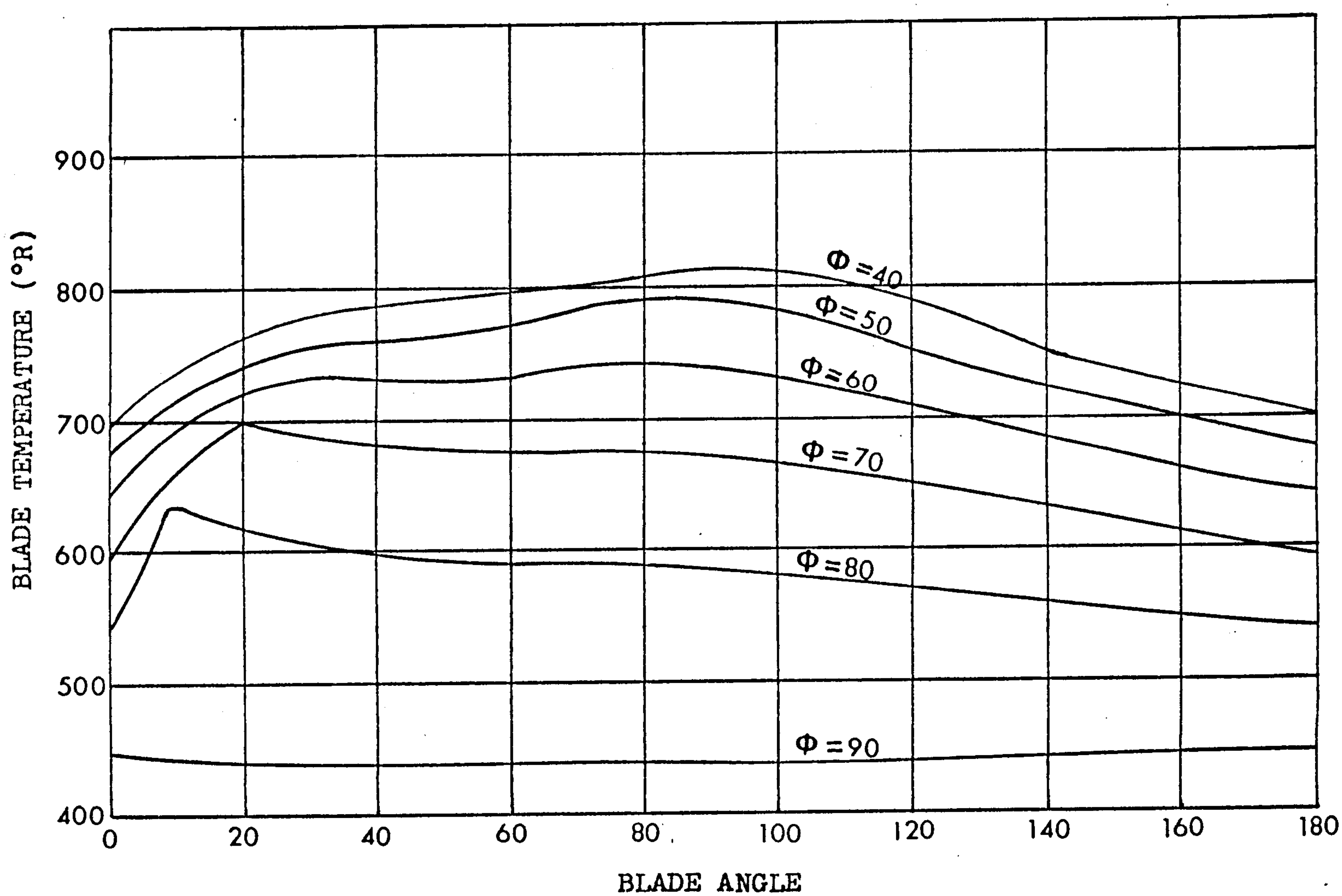

FIGURE 3 TEMPERATURE OF LOUVER BLADES

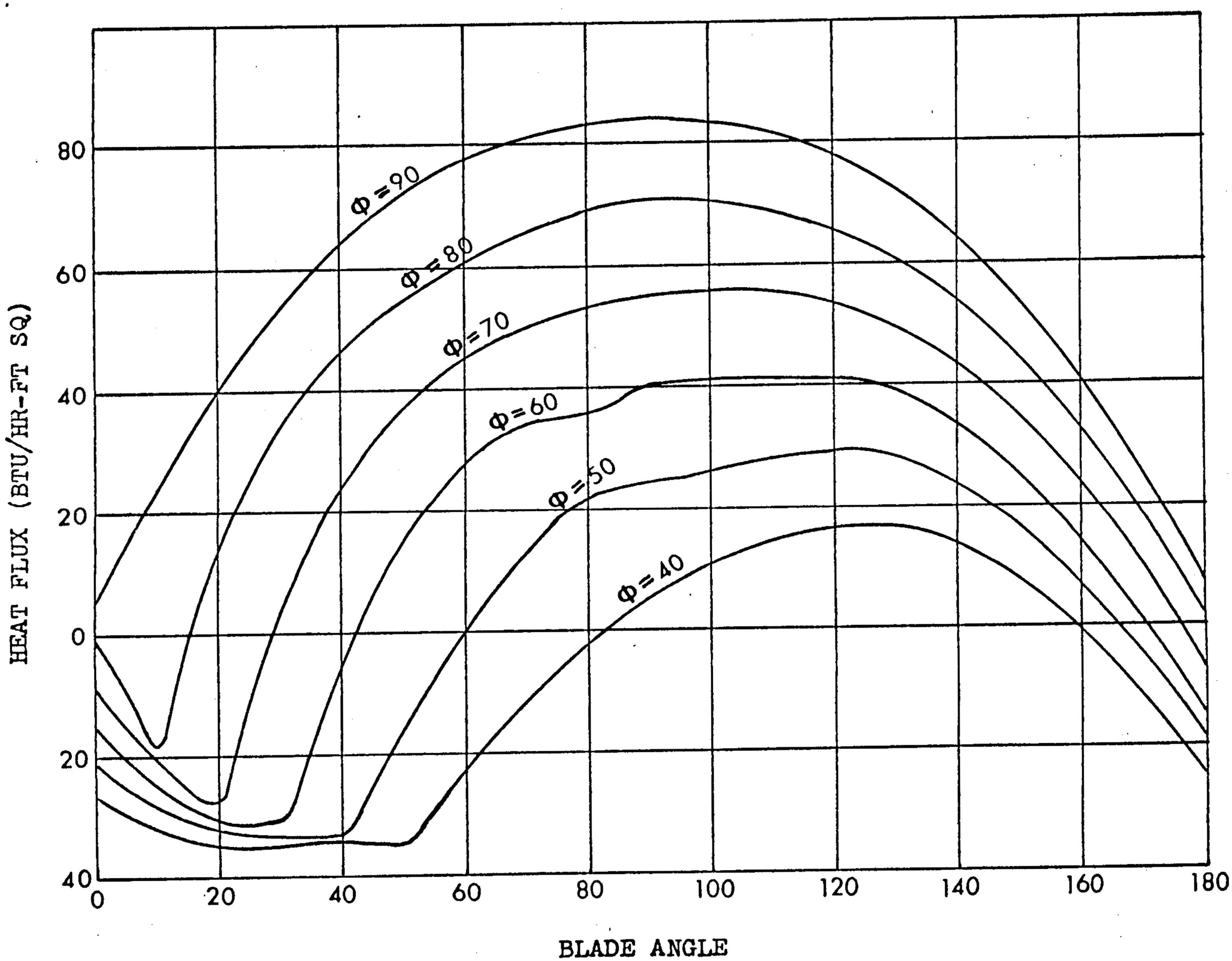

FIGURE 4 HEAT REJECTION CAPABILITY OF BASE SURFACE

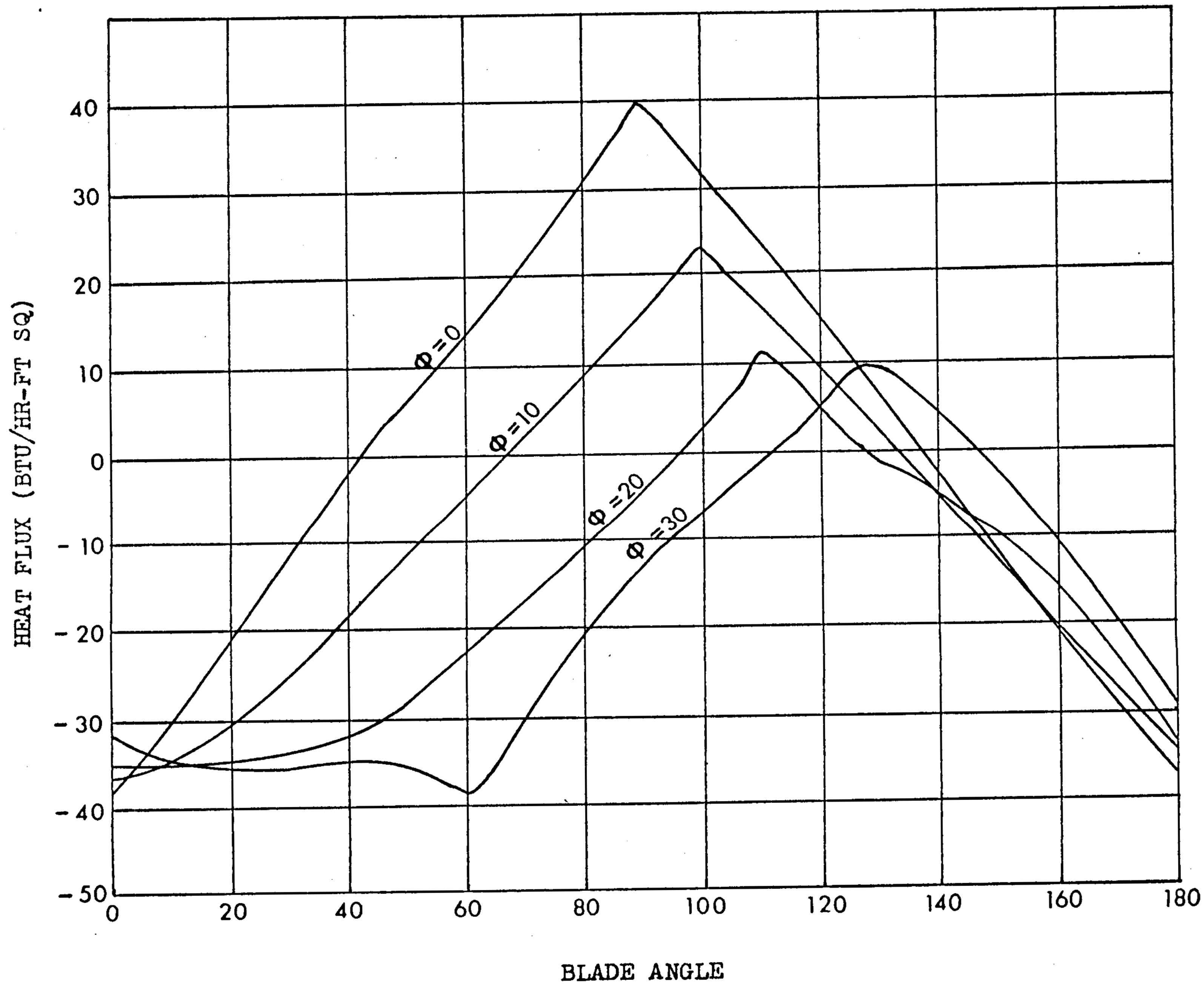

FIGURE 5 HEAT REJECTION CAPABILITY OF BASE SURFACE