approach would consider the end game as a differential game similar to Isaacs' "game of two cars"[3] with payoff being miss distance. The missile would maneuver so as to minimize the payoff while the target would try to maximize it. If either played nonoptimally, the other would achieve a better payoff.

The end game study is, however, outside the scope of this Note.

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Assessment of an Active Thermal Control Louvre Array for Spacecraft

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Louvre Array Thermal Design

LOUVRE arrays are used on spacecraft mainly for the control of instrument cabin temperature and work on the principle of opening and closing of louvre blades to suit environmental and spacecraft heat load conditions.[1,2]

The test model shown in Fig. 1 consists of three louvres supported at each end by stainless steel pins in P.T.F.E. bearings and mounted such that this combination is above a heated honeycomb panel which serves as the main radiator surface and simulates conditions of heat generation in the spacecraft. The louvres are actuated by flat spiral bimetallic springs mounted at one end of the louvre blades, shown in Fig. 1. The springs or actuators uncoil with rise in temperature of the actuator housing causing the louvre blades to open and ventilate excess heat to black space by radiative heat transfer. A fall in temperature of the actuator housing leads to the eventual closure of the louvre blades thereby isolating the spacecraft interior from black space and conserving the heat generated inside the spacecraft. The louvre array together with the spiral spring actuator and housing form an elaborate temperature control of spacecraft temperature. As heat transfer from the spacecraft to black space is by radiation the emissivity of the louvre array is an important factor in its thermal design. In the fully closed position the emissivity of the array is low being that of the polished aluminium blades. In the fully open position, the emissivity of the array is high being that of the matt black radiator base, which simulates conditions of heat generation inside the spacecraft. For intermediate blade positions the emissivity of the louvre array is calculated in the following manner. For unit depth of louvre array: total base area $= 6L$; area of base exposed normal to surface $= 6L(1-\cos\theta)$; area of louvre exposed normal to surface $= 6L\cos\theta$. Thus the effective emissivity is

$$\varepsilon = \frac{6L(1-\cos\theta)}{6L}\times 0.8 + \frac{6L\cos\theta}{6L}\times 0.5 \tag{1}$$

where the significance of L and θ is clearly illustrated in Fig. 1.

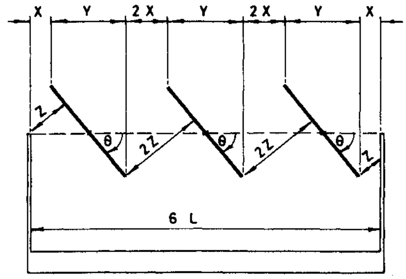

Fig. 1 The geometry of the louvre array.

However, a more accurate assessment of the exposed base area would be obtained by taking the normal distance between the louvres, i.e., the Z dimension in Fig. 1 giving the area of base exposed as $6L\sin\theta$ and

$$\varepsilon = \frac{6L\sin\theta}{6L}\times 0.8 + \frac{6L\cos\theta}{6L}\times 0.5$$

i.e.

$$\varepsilon = 0.8\sin\theta + 0.5\cos\theta \tag{2}$$

assuming emissivity of the matt black surface as 0.8 and emissivity of the louvres as 0.5. Equations (1) and (2) give the relationship between the effective emissivity of the system and the angular position of the blades. For temperature control purposes, the louvres are made to respond to the radiator base temperature which in effect is the temperature inside the spacecraft. At a base temperature of 10°C the actuators were positioned such that the louvre blades were in the fully closed ($\theta = 0°$) position. The actuators responded to any increase in base temperature, opening the louvres, to a maximum ($\theta = 90°$) at a base temperature of 25°C. The temperature control system was designed to be fully responsive to a temperature change of only 15°C.

Spiral Spring Actuators

The bimetallic strip from which the spiral spring actuators are made give sufficient expansion to cause rotation of the louvre blades through 90° for a temperature change of 15°C.

The spring material chosen was a nickel/iron alloy readily available. Two factors important in spiral spring design are θ, the angular rotation of the spiral spring spindle, and R the restraining torque and are given by Martin and Yarworth[3] as follows:

$$\theta = \frac{130Kl(\Delta T)_M}{t} \tag{3}$$

and

$$R = 0.189KEBt^2(\Delta T)_F \tag{4}$$

R is of the order of 0.005 oz in. as determined from bearing data and louvre dimensions.

The design values for l, t, and B are determined from Eqs. (3) and (4) bearing in mind the availability of the bimetallic strip from which the spiral springs are made. The values of these dimensions are $t = 0.012$ in., $B = 0.118$ in., and $l = 42.5$ in. Weaker springs were considered, but these were too easily damaged by handling.

Test Model Modification

A parameter of some importance in assessing the performance of louvre arrays is the open/closed power rejection ratio, a low value of the parameter implying in general an inefficient louvre-array system. An initial louvre array gave an open/closed power rejection ratio of 3:1 which was lower than desired for space application. Heat losses were excessively high and there was little thermal coupling between the base and the actuator. The thermal coupling by conduction through the spiral spring was clearly ineffective. The modifications carried out on a later model of the louvre array were as follows.

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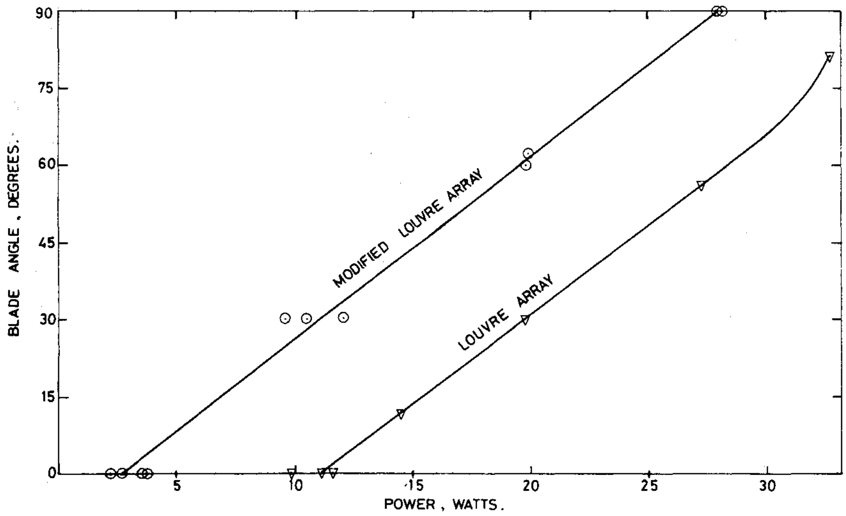

Fig. 2 Power rejection curve of the louvre array.

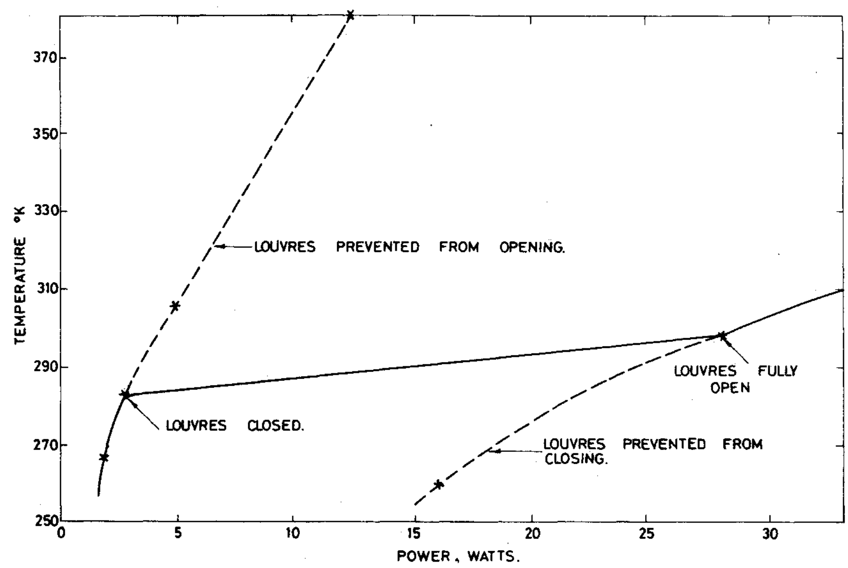

Fig. 3 Base temperature variation for the louvre array.

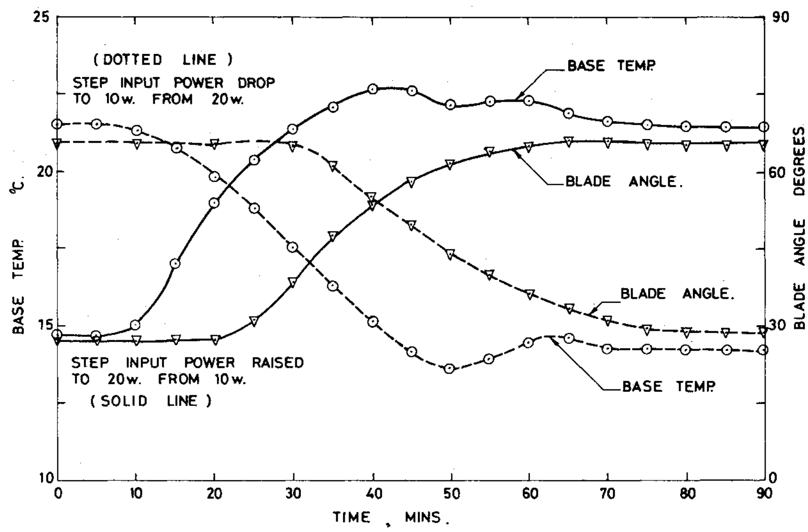

Fig. 4 Dynamic response of the louvre array.

a) Complete reinsulation of the model was undertaken and no part of the insulation was under compression on corners or edges. The louvre blades were improved by covering with a single sheet of aluminized Melinex.

b) The thermal coupling from the base to the actuator was improved by arranging for radiative thermal coupling. The housing was made of 16 SWG alloy fixed firmly to the base with seven bolts so that heat from the base conducted up through the housing and radiated off the black face on to the actuators.

Test Program

The louvre array was tested for actuator response and sensitivity from which the open/closed power rejection ratio which is also a measure of the heat load efficiency, for the array, was derived. During the tests, conditions of black space had to be simulated. The simulation was achieved by fixing a black faced shroud to a vacuum chamber cooled to −200°C using liquid nitrogen. The louvre blades were adjusted to operate within the required temperature range, i.e., closed at 10°C and fully open at 25°C. The heater operating temperature was slowly increased across this temperature range and the angular position of the louvre noted after thermal equilibrium was obtained for every setting of the heater temperature.

The test was repeated with the heater temperature reduced slowly across the same temperature range. This test was carried out to determine how closely the actuators followed the base temperature. The dynamic angular positional response of the louvre blades to a step input power of 20w to the heater was then studied till a steady state was obtained and the test was further repeated for a negative step input, also of 20w.

Experimental Results and Discussion

The test results are illustrated graphically. Figure 2 shows the power rejected by the array against the blade angle. A power rejection ratio in the open/closed position of 11:1, easily calculated from Fig. 2, was obtained which is a distinct improvement over the ratio 3:1 also shown in Fig. 2, before modifications described earlier were carried out.

In Fig. 3 is shown the variation of the base temperature, with the power rejected and shows how effectively the system controls the temperature for the large range of power—a function important in spacecraft application. Figure 3 also shows what temperatures would be obtained should the louvres either fail to open or close. In Fig. 4 is shown the dynamic response of the actuators to step inputs of power, either increasing or decreasing. In both cases the total response time is of the order of 90 min. It is also evident that about 4°C temperature difference between base and actuator is required before the latter begins to move but this settles to 1°C under steady-state conditions. This is possibly due to thermal lags and bearing friction. The shape of the response curves indicates slightly underdamped conditions.

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Optimum Design of Elastomeric Gaskets for Combined Thermal and Vibration Performance

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Nomenclature

E = Young's modulus, psi
h_c = contact conductance coefficient, Btu/hr sq ft °F
Q/A = heat flux, Btu/hr sq ft
ΔR = attenuation, dB
ΔT = temperature difference °F
t = interstitial material thickness, in.
δ_0 = initial thickness between surfaces, μin.
ρ = density, lbm/ft^3
ω = vibration frequency, rad/sec

Subscripts
i = interstitial elastomer
mj = metallic junction

Introduction

THE design and development of new spacecraft systems requires a continual re-evaluation and optimization of existing components. In order to optimize spacecraft components, problems associated with both thermal and vibration transmission across metallic junctions must be considered. Many of these junctions involve the use of elastomeric gaskets as a means of component sealing, thermal isolation or enhancement, and/or vibration isolation. These gaskets are often used in the miniaturization and refinement of electronic components which must be maintained at a present environment despite extreme temperature gradients, heat fluxes, and system vibrations. A schematic of the effect of elastomeric gaskets on these thermal and vibration characteristics is shown in Fig. 1.

These spacecraft optimization problems suggest the need for a new and more refined gasket design technique. Generally, design merit functions are established for the variables involved in a system. When these design merit functions are competitive, the usual compromise is to employ a tradeoff function. Occasionally, however, the merit functions are not in opposition and may be used to establish a truly optimum design. Such a situation arises in the design of elastomeric gaskets and a technique for use of these materials is presented in this Note.

Design Technique

Elastomeric materials are useful as gaskets because of their superior resistance to many types of environments, their excellent sealing capabilities, and their durability through repeated loadings. Selected neoprene, fluorocarbon, nitrile, polyacrylate, and silicone elastomers are considered in the present analysis. Many of these elastomeric materials contain various fillers to improve their mechanical or thermophysical properties. Elastomer fillers include such materials as carbon black, graphite, metallic flakes or powder, silica, and various oxides, as indicated in Table 1.

The thermal contact conductance of a junction with or without interstitial or gasket materials, provides a measure of the heat-

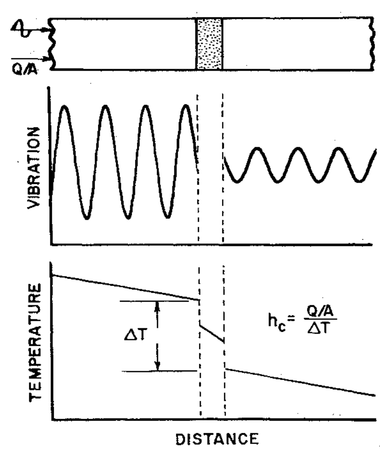

Fig. 1 Schematic of the effect of an elastomeric gasket on the thermal and vibration characteristics of a metallic junction.

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