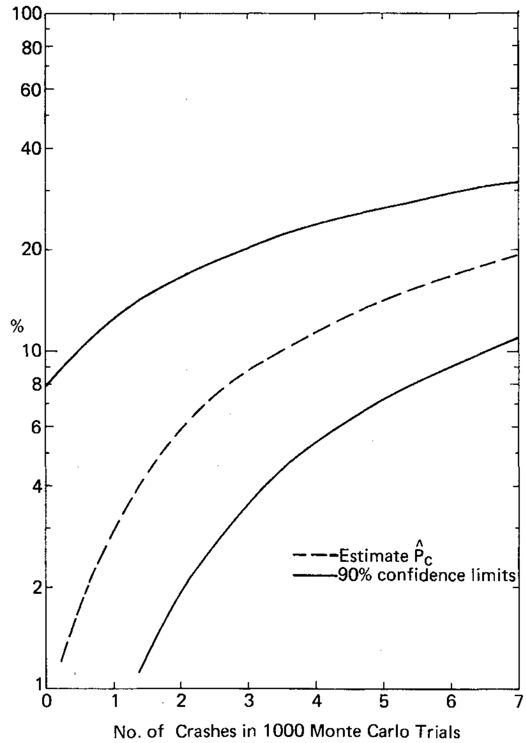

Fig. 4 90% confidence limits for P_c in 30 independent intervals based on 1000 Monte Carlo trials.

large number of trials also lead to unreliable estimates of $\hat{P}_c$ when extrapolated. This suspicion is confirmed for example with, say one crash observed in 1000 Monte Carlo trials giving $\hat{p}=0.1\%$ with 90% confidence limits of 0.02% and 0.45%. When extrapolated to obtain the probability of crashing for 30 trials the estimate $\hat{P}_c$ is 3% while the 90% confidence limits are 0.7% and 12.6%. These results are included in Fig. 4, which gives confidence limits for various numbers of observed crashes. It is concluded that, even with a large number of trials, Monte Carlo methods are unreliable for estimating small values of probability of crashing.

Summary

Confidence limits are obtained for the probability of crashing based on the estimate provided by Monte Carlo simulation. This involves extrapolating the confidence limits for the probability of crashing for a single independent interval of terrain, to the desired terrain length. The method indicates how many independent intervals are needed in a given case before P_c and the estimate $\hat{P}_c$ are close.

Conclusions

1) Even with large numbers of trials, Monte Carlo methods are unreliable for estimating *small* values of P_c. Some other method, for example as suggested in Ref. 1, should be used.

2) With a sufficient number of trials, large values of P_c may be estimated with reasonable accuracy. However such large P_c values would automatically indicate that higher clearances be flown to reduce P_c and so one is still faced with the problem of a reliable estimate of the new smaller P_c values.

References

[1]Cunningham, E.P., "The Probability of Crashing For a Terrain-Following Missile," *Journal of Spacecraft and Rockets,* Vol. 11, April 1974, pp. 257-260.

[2]Burington, R.S., and May, D.C., *Handbook of Probability and Statistics,* McGraw-Hill, New York, 1970, p. 247.

Development of a Multipurpose Radiometer

Reagan S. Redman*
NASA JSC, Houston, Texas
and
Calvin M. Wolff†
Northrop Services, Inc., Houston, Texas

Introduction

THE early programs conducted in the large thermal-vacuum chambers at the Johnson Space Center (JSC) (circa 1966) involved measurement of thermal irradiance in the solar spectral region (0.25 to 2μ). A split-disc bolometer was used on these tests because it was the only commerically available instrument that had a flat spectral response over the solar spectral region and could operate within the thermal-vacuum environment.

As thermal-vacuum testing evolved in the ensuing years, it became necessary to measure irradiance in the infrared spectral region (0.8 to 20μ). The split-disc bolometer was not suitable in that its window would not transmit energy at wavelengths longer than 2μ. A Boelter-Schmidt-type thermopile with a black matte finish on the sensor surface was chosen for use in the infrared spectral region.

The two instruments coexisted for many years, each performing its own function. Eventually, technical and economic demands created a requirement for a single instrument that could be utilized in both spectral regions and could withstand the thermal-vacuum environment.

As a result, a program was initiated to develop such an instrument. The product of this development program is a hybrid thermal-type sensor. It incorporates the split-disc, windowed design of the bolometer to allow it to perform in the solar spectral region, but is easily convertible to infrared usage by removal of the window.

Description of Radiometer

The instrument consists of two semicircular Boelter-Schmidt-type sensors, i.e., split-disc. The sensors are copper constantan wire wound around an electrically insulative core with one-half of the winding copper plated (Fig. 1). The sensors are mounted adjacent to each other on a cylindrical aluminum base and painted with a black matte finish. The output leads from the sensors and a thermocouple extends from the side of the base.

A heater provides a stable base temperature for thermal-vacuum applications. The heater consists of two independent thermostatically controlled heaters mounted in an aluminum cylinder the same diameter as the radiometer base. The heater, operating off 100 V (ac), controls the radiometer base at approximately 90° ± 3°F.

The Boelter-Schmidt-type sensors were selected for this radiometer because they are very rugged and measure heat transfer, regardless of mode (absorption, emission, conduction, convection). The versatility of the radiometer is due to its split-disc configuration and the data-reduction technique used to determine the heat transferred into the sensors by each mode, or a selected combination of modes.

Presented as Paper 78-1616 at the 10th AIAA/IES/ASTM Space Simulation Conference, Bethesda, Md., Oct. 16-18, 1978; submitted Dec. 1, 1978; revision received April 6, 1979. This paper is declared a work of the U.S. Government and therefore is in the public domain.

Index categories: Radiation and Radiative Heat Transfer; Spacecraft Testing, Flight and Ground; Solar Thermal Power.

*Aerospace Engineer, Space Environment Test Division.

†Senior Scientist.

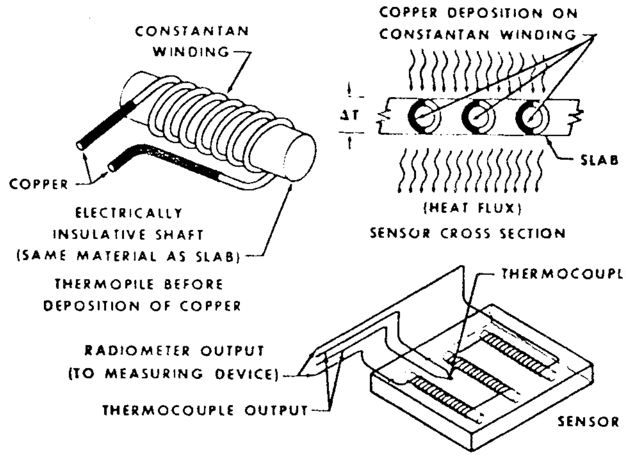

Fig. 1 Meter design principle.

The sensors may be considered as elements in a thermal circuit in which heat flow is measured by the temperature differential across them, just as current flow is measured by the voltage differential across a low-value resistor.

For measuring irradiance in the solar spectral region, the radiometer is outfitted with a half-silvered quartz window similar to the window used in the split-disc bolometer commonly used in solar simulation practice. The window is circular; one half is clear, with the other half having a vacuum-deposited aluminum coating. The window is mounted on the radiometer so that the aluminum is used as a second surface reflector. The back side of the aluminum is coated with a black matte paint, so both sensors view a surface of high emittance (the quartz also has a very high emittance). In this configuration, the sensor covered with the second surface mirror receives radiation only from the quartz, whereas the sensor viewing through the clear quartz receives transmitted radiation as well as that emitted by the quartz. If the negative electrical outputs of the two radiometers are tied together, the positive output of the mirrored sensor is connected to the negative terminal of a millivoltmeter, and the positive lead of the unmirrored sensor is connected to the positive terminal, the radiometer will measure the net transmitted radiation through the window only, being a single compensated radiometer.

Combined solar and infrared irradiance can be measured by either sensor when no window is employed. The signal received is proportional to the net heat transferred through the sensor. To determine the irradiance on the sensor, the quantity σT_R^4 must be added to the net transfer value (T_R = radiometer temperature, σ = Stefan-Boltzman constant). An emissive value is not necessary because, assuming the black matte coating is a "gray" surface, absorptivity is the same as emissivity. If the radiometer is calibrated for irradiance, no adjustment in the amount of calculated emissive power is necessary.

Following prototype testing and a redesign of the window bezel, sixty production-model radiometers were purchased. Each of the production-model radiometers were performance tested and calibrated. These tests were performed at ambient and vacuum environments. Physical and performance characteristics of the radiometers are listed in Table 1.

Table 1 Physical and performance characteristics of radiometers (averages of test results)

Diameter, in.	1.5
Depth, in.	1.0
Weight with window, oz.	
Without heater	5
With heater	10
Coating on sensor	3M Nextel 410C black
Range, Btu/ft $^{-2}$/h $^{-1}$	0 to 1320
Sensitivity	
With window (solar), Btu/ft $^{-2}$/h $^{-1}$/mV $^{-1}$	16
Without window (infrared), Btu/ft $^{-2}$/h $^{-1}$/mV $^{-1}$	7.2
Time constant of response, s	1.25
Sensitivity air/sensitivity vacuum	0.98
Drift in signal at one solar constant, windowed configuration, temperature range $-50°$ F to $+92°$ F, %	1.0

Radiometer Applications

The split-disc configuration lends itself to a unique application in that the radiometer can be used to determine the solar absorptance and herispherical emittance for thermal control coatings.

If a sufficiently thin (0.005-in. or less) layer of a surface coating is applied on one sensor surface and the other sensor is left black, the emittance can be determined as follows:

Total hemispherical emittance at 90°F

$$\epsilon = \left\{\frac{\text{mV. coated sensor}}{\text{mV. black sensor}}\right\} \times \left\{\frac{\text{sen. coated sensor}}{\text{sen. black sensor}}\right\} \times \{\text{emittance of black surface}\} \tag{1}$$

If the windowless radiometer, in a vacuum chamber at less than 10^{-5} Torr atmosphere, views radiation from a solar simulator of good spectral quality, the solar absorptance of the unknown surface is determined as follows:

Solar absorptance

$$\alpha = \left\{\frac{\text{mV. coated sensor}}{\text{mV. black sensor}}\right\} \times \left\{\frac{\text{sen. coated sensor}}{\text{sen. black sensor}}\right\} \times \{\text{solar absorptance of black surface}\} \tag{2}$$

In a similar manner, when a thin layer of surface coating is applied to the sensor surface, the windowless radiometer irradiance is absorbed from a solar simulator by a spectrally selective coating. This technique has been utilized successfully to measure the absorbed flux on a Shuttle Orbiter radiator panel (coated with silver-backed Teflon) from an infrared lamp array that operated over an extremely broad spectral range. This particular coating has a very low absorptance in the solar region (0.05) yet has a high emittance (0.8) in the infrared region. The lamp array was required to provide absorbed irradiance levels between 20 and 190 Btu/ft $^{-2}$/h $^{-1}$.

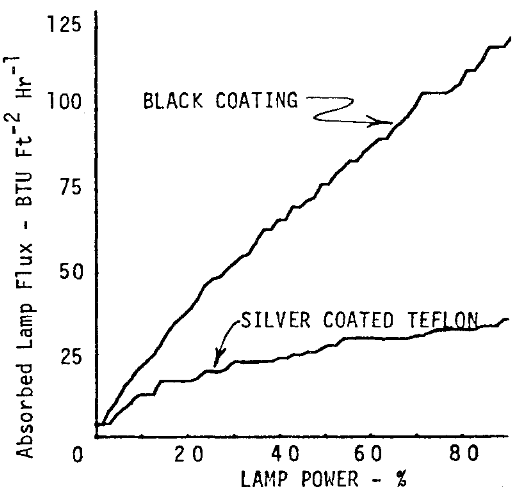

Fig. 2 Coating comparison.

This broad range of irradiance levels necessitated applied voltages between 10 V (dc) and 120 V (dc) to be applied to the lamps. This range of applied voltages in turn caused the radiant output of the lamps to undergo very large spectral shifts. To integrate the absorptance of the test article surface with the spectral distribution of the lamp output over the almost infinite number of spectral distributions involved would be approaching an impossible task. By utilizing the technique of applying the thermal-control coating directly to the radiometer sensor surface, a direct integration of the irradiance absorbed by the test article was performed with the radiometer. Figure 2 is a plot of the irradiance absorbed as a function of the applied voltage on the simulator lamp. The upper curve is the irradiance absorbed for a black matte finish and the lower curve is the irradiance absorbed for the test article thermal control coating.

Conclusions

These radiometers have been in use in the JSC thermal-vacuum chambers for approximately eighteen months. During this period, no significant variations in the performance characteristics of the radiometers have been discerned and they have met or exceeded all expectations concerning their performance, stability, and versatility. The light weight and compactness of the radiometer makes it very amenable for use in remote test configurations. With the thermostatically controlled heater assembly, the radiometer can be used in a thermal-vacuum environment where it is subjected to varying irradiance levels (full sun to no sun) without any external temperature compensation. This self-contained temperature-compensation capability, in addition to providing high sensitivity and fast response, makes the radiometer ideally suited for use with the scanning systems used to monitor the solar simulator systems in the JSC chambers. An additional advantage gained by this radiometer is that its signal is self-generating, as opposed to the bolometer devices it replaced, which required a bridge excitation and balancing circuit located in the chamber control room. Each time a test was run, the bolometer radiometers had to be calibrated in situ before and after the test, which was a slow and costly procedure. The new radiometers eliminated the variables introduced by the external circuitry and the requirement for an in situ calibration. Thus, a considerable reduction in operating cost is realized.