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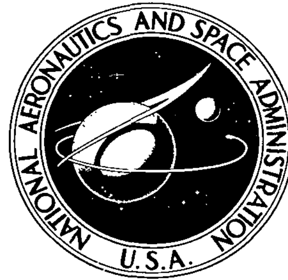

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A METHOD OF TREATING THE NON-GREY ERROR IN TOTAL EMITTANCE MEASUREMENTS

by James B. Heaney and John H. Henninger

Goddard Space Flight Center
Greenbelt, Md. 20771

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION • WASHINGTON, D. C. • DECEMBER 1971

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1. Report No.
NASA TN D-6501

2. Government Accession No.

3. Recipient's Catalog No.

4. Title and Subtitle

"A Method of Treating the Non-Grey Error in Total Emittance Measurements"

5. Report Date
December 1971

6. Performing Organization Code

7. Author(s)
James B. Heaney and John H. Henninger

8. Performing Organization Report No.
G-1026

9. Performing Organization Name and Address
Goddard Space Flight Center
Greenbelt, Maryland 20771

10. Work Unit No.

11. Contract or Grant No.

12. Sponsoring Agency Name and Address
National Aeronautics and Space Administration
Washington, D. C. 20546

13. Type of Report and Period Covered
Technical Note

14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract

In techniques presently available for the rapid determination of total emittance, the sample is generally exposed to surroundings that are at a different temperature than the sample's surface. When the infrared spectral reflectance of the surface is spectrally selective, these techniques introduce an error into the total emittance values. Surfaces of aluminum overcoated with oxides of various thicknesses fall into this class. Because they are often used as temperature control coatings on satellites, their emittances must be accurately known. The magnitude of the error was calculated for Alzak and silicon oxide-coated aluminum and was shown to be dependent on the thickness of the oxide coating. The results demonstrate that, because the magnitude of the error is thickness-dependent, it is generally impossible or impractical to eliminate it by calibrating the measuring device.

17. Key Words Suggested by Author
Total emittance
Thermal control

18. Distribution Statement
Unclassified-Unlimited

19. Security Classif. (of this report)
Unclassified

20. Security Classif. (of this page)
Unclassified

21. No. of Pages

22. Price*
$3.00

*For sale by the National Technical Information Service, Springfield, Virginia 22151

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A METHOD OF TREATING THE NON-GREY ERROR IN TOTAL EMITTANCE MEASUREMENTS

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INTRODUCTION

One problem that arises in the design of satellites is the variation in material properties between samples chosen for study and pieces actually used in fabrication. Because of the difficulties involved in determining material properties after assembly, engineers often rely on measurements obtained from materials prior to assembly, or on data taken from samples selected as being representative of the material used. This problem is especially crucial for thermal control surfaces and solar cell arrays where system performance is strongly dependent upon the surface condition as defined by its solar absorptance, α, and thermal emittance, ϵ_T.

Surface materials used in spacecraft thermal control systems are selected on the basis of their having solar absorptance and thermal emittance values compatible with the mission's temperature requirements. It has been shown that highly reflecting aluminum surfaces overcoated with dielectric films of varying thickness can produce a wide variety of coatings, with different α/ϵ_T values (References 1, 2). These dielectric films are non-absorbing in the solar wavelength region but rely on a combination of interference and absorption effects to give high infrared emittances. The α is essentially independent of thickness, while ϵ_T increases steadily with increasing thickness of the dielectric film. For a certain range of thickness, ϵ_T is strongly thickness-dependent, so a slight change in thickness can cause a rather large change in emittance. This property implies that the thickness must be carefully controlled and monitored. Surfaces of this type exhibit a spectrally varying infrared reflectance as a result of the combination of absorption and interference effects. This arrangement often provides a compensating form of temperature control as a byproduct, since emittance increases with temperature when the proper dielectric film thickness is chosen.

The emittance is a sensitive function of the dielectric film thickness because the infrared reflectance is determined by the thickness-controlled depth of absorption bands. This spectral selectivity of the infrared reflectance causes the non-grey error in devices commonly used for the rapid determination of total emittance, and it has been shown (Reference 3) that this error can be quite large. Although it is often possible to eliminate this error through proper calibration with samples of known emittance, the report shows that when the emittance is thickness-dependent, calibration is either impossible or impractical. Therefore, the magnitude of the error must be determined for the type of device used. The choice of instrumentation is generally intended to satisfy the engineer's need to correlate laboratory sample data with measurements performed on actual flight hardware. Several commercially available instruments permit the ϵ_T of a spacecraft

surface to be rapidly determined, after assembly, in a non-destructive manner. They all involve the determination of total emittance and are therefore subject to the non-grey error.

EXPERIMENTAL TECHNIQUES

Total emittance measurements were performed with a Gier-Dunkle Model DB-100 portable infrared reflectometer. This device produces a weighted value of the reflectance of an opaque sample, from which the emittance is determined. The measurement, performed relative to high and low reflectance standards, is instantaneous and independent of surface temperature between 293K and 333K. Through the use of a selective filter, the non-grey error is minimized, but (as shown in the following calculations) not eliminated. The operating principles and design details of a prototype of this device have been presented in the literature (Reference 4). However, as this analysis proceeds, it will be necessary to briefly describe the instrument's features for clarity and in support of the arguments.

The values of relative weighted reflectance are obtained from Hohlraum measurements. Any surface covering the sample port is alternately exposed to omni-directional radiation emitted by hot and cold semicylinders acting as black body cavities. The radiant flux reaching the detector from the exposed area is given by

$$\int_{A_D} \int_{A_S} I_S \frac{\cos \theta_S \cos \theta_D}{{r_{SD}}^2} \, d\,A_S \, d\,A_D ,$$

where

A_S = illuminated area of the sample,

A_D = effective viewing aperture area of the detector,

θ_S, θ_D = angle between the indicated surface normals and the path, r_{SD}, followed by the radiant flux, and

I_S = Hohlraum radiation reflected by the surface in the direction r_{SD} .

Since the illuminated area is viewed by the detector in a near-normal direction, all parameters dealt with in the following analysis are considered to be averaged over the solid angle subtended by this area. For example, when the term reflectance, ρ, is used it is understood that

$$\rho = \frac{\int_{A_D} \int_{A_S} \rho\,(\theta) \frac{\cos \theta_S \cos \theta_D}{r_{SD}^2} \, d\,A_S \, d\,A_D}{\int_{A_D} \int_{A_S} \frac{\cos \theta_S \cos \theta_D}{r_{SD}^2} \, d\,A_S \, d\,A_D} ,$$

where $\rho(\theta)$ is the more correct angular-dependent parameter. For the infrared region considered here and for the narrow viewing angle used in this device, it is safe to say that $\rho = \rho(\theta)$ and $\epsilon = \epsilon(\theta)$.

When a test surface covering the viewing port of the instrument's sensing head is irradiated by the rotating semicylindrical cavities, an alternating signal is produced in the detector because the cavities are at different temperatures. The intensity of radiant flux coming from the direction of the sample when irradiated by the hotter cavity is

$$I_{S_H} = \epsilon_S (T_S)\, \tau (T_S)\, \sigma T_S^4 + \rho_S (T_S, T_H)\, \tau (T_S, T_H)\, \sigma T_H^4 + C\ , \tag{1}$$

where

$\epsilon_S(T_S)$ = near-normal emittance for a sample at temperature T_S ,

$\rho_S(T_S, T_H)$ = near-normal reflectance for a sample at temperature T_S when irradiated by the surrounding cavity walls at T_H ,

$\tau(T_S, T_H)$ = transmittance of a polyethelene compensating filter used to modify the spectral distribution of radiant energy reaching the detector,

σ = Stefan-Boltzmann constant, and

C = a term used to include all other sources of emitted or reflected energy reaching the detector.

Similarly, when the surface is exposed to the colder cavity,

$$I_{S_C} = \epsilon_S (T_S)\, \tau (T_S)\, \sigma T_S^4 + \rho_S (T_S, T_C)\, \tau (T_S, T_C)\, \sigma T_C^4 + C\ . \tag{2}$$

Equations (1) and (2) show that only the reflected energy varies with this alternate irradiation by the two semicylinders. The detector amplifying system is made to respond only to the alternating signal arising in the reflectance terms (Reference 4), so the fluctuating portion of the signal is the difference between Equations (1) and (2). That is,

$$K V_S = I_{S_H} - I_{S_C} = \rho_S (T_S, T_H)\, \tau (T_S, T_H)\, \sigma T_H^4 - \rho_S (T_S, T_C)\, \tau (T_S, T_C)\, \sigma T_C^4\ , \tag{3}$$

where the voltage, V_S , of the output signal is proportional (K) to the energy difference. The constant K includes the detector sensitivity, which is considered to be an invariant function of all the explicit and implicit variable parameters of Equation (3). Equation (3) represents the case for an unknown sample covering the opening of the sensing head. The instrument must be calibrated by establishing known voltage levels to define the range of the output signal. This is done using high and low reflectance standards, resulting in the following intensity equations for each case:

$$K V_{100} = \rho_{100}\, (T_S, T_H)\, \tau (T_S, T_H)\, \sigma T_H^4 - \rho_{100}\, (T_S, T_C)\, \tau (T_S, T_C)\, \sigma T_C^4\ , \tag{4}$$

$$K V_0 = \rho_0\, (T_S, T_H)\, \tau (T_S, T_H)\, \sigma T_H^4 - \rho_0\, (T_S, T_C)\, \tau (T_S, T_C)\, \sigma T_C^4\ . \tag{5}$$

Here $\rho_{100}(T_S, T_H)$ and $\rho_0(T_S, T_H)$ are the reflectances of the high and low standards, respectively, and V_{100} and V_0 are the corresponding voltages of the output signal.

If the high and low reflectance standards have no spectral variation in reflectance over the wavelength range specified by the planckian distributions for σT_H^4, σT_C^4, and σT_S^4, and the surface properties of the materials are invariant over the temperature range of T_H, T_C, and T_S, then the references are "grey" reflectors (Reference 5). That is,

$$\rho_{100}(T_S, T)\,\sigma T^4 = \rho_{100}(T_S)\,\sigma T^4,$$

and

$$\rho_0(T_S, T)\,\sigma T_4 = \rho_0(T_S)\,\sigma T^4.$$

Equations (4) and (5) then become

$$K V_{100} = \rho_{100}(T_S)\left[\tau(T_S, T_H)\,\sigma T_H^4 - \tau(T_S, T_C)\,\sigma T_C^4\right], \tag{6}$$

$$K V_0 = \rho_0(T_S)\left[\tau(T_S, T_H)\,\sigma T_H^4 - \tau(T_S, T_C)\,\sigma T_C^4\right]. \tag{7}$$

The measured reflectance is given by

$$\rho_S(T_S, T_H, T_C) = \frac{V_S - V_0}{V_{100} - V_0}. \tag{8}$$

Substituting Equations (3), (6) and (7) into Equation (8) gives, for the measured reflectance,

$$\rho_S(T_S, T_H, T_C) = \frac{\left[\rho_S(T_S, T_H)\tau(T_S, T_H)\sigma T_H^4 - \rho_S(T_S, T_C)\tau(T_S, T_C)\sigma T_C^4\right] - \rho_0(T_S)\left[\tau(T_S, T_H)\sigma T_H^4 - \tau(T_S, T_C)\sigma T_C^4\right]}{\rho_{100}(T_S)\left[\tau(T_S, T_H)\sigma T_H^4 - \tau(T_S, T_C)\sigma T_C^4\right] - \rho_0(T_S)\left[\tau(T_S, T_H)\sigma T_H^4 - \tau(T_S, T_C)\sigma T_C^4\right]}.$$

This reduces to

$$\rho_S(T_S, T_H, T_C) = \frac{\left[\rho_S(T_S, T_H)\tau(T_S, T_H)\sigma T_H^4 - \rho_S(T_S, T_C)\tau(T_S, T_C)\sigma T_C^4\right]}{\left[\rho_{100}(T_S) - \rho_0(T_S)\right]\left[\tau(T_S, T_H)\sigma T_H^4 - \tau(T_S, T_C)\sigma T_C^4\right]} - \frac{\rho_0(T_S)}{\left[\rho_{100}(T_S) - \rho_0(T_S)\right]}. \tag{9}$$

When $\rho_{100}(T_S)$ and $\rho_0(T_S)$ are accurately known from independent measurements, the voltages V_{100} and V_0 can be proportionately scaled so that $\rho_{100}(T_S) \simeq 100\%$ and $\rho_0(T_S) \simeq 0\%$. Equation (9) then reduces to

$$\rho_S(T_S, T_H, T_C) = \frac{\left[\rho_S(T_S, T_H)\tau(T_S, T_H)\sigma T_H^4 - \rho_S(T_S, T_C)\tau(T_S, T_C)\sigma T_C^4\right]}{\left[\tau(T_S, T_H)\sigma T_H^4 - \tau(T_S, T_C)\sigma T_C^4\right]}. \tag{10}$$

If, by chance, $\rho_S(T_S, T_H, T_C)$ is also the reflectance of a "grey" surface such that

$$\rho_S(T_S, T)\,\sigma T^4 = \rho_S(T_S)\,\sigma T^4$$

as defined previously, then Equation (10) reduces further to

$$\rho_S(T_S, T_H, T_C) = \rho_S(T_S). \tag{11}$$

That is, for a grey reflector, the reflectance determined in this measurement is equal to the true reflectance by definition.

Equation (11) represents a special case. The more general expression of Equation (10) includes the possibility of a sample whose spectral reflectance is non-grey. It would be erroneous to assume that Equation (11) is valid for all samples and that the measured reflectance is the true reflectance. Such an assumption would permit the measurement to be compromised by the so-called "non-grey error."

To include the more general "non-grey" case, the parameters of Equation (10) are replaced by their wavelength-dependent equivalents. Equation (10) then becomes

$$\rho_S(T_S, T_H, T_C) = \frac{\int_0^\infty \rho_\lambda(T_S)\tau_\lambda(T_S)E_\lambda(T_H)\,d\lambda - \int_0^\infty \rho_\lambda(T_S)\tau_\lambda(T_S)E_\lambda(T_C)\,d\lambda}{\int_0^\infty \tau_\lambda(T_S)E_\lambda(T_H)\,d\lambda - \int_0^\infty \tau_\lambda(T_S)E_\lambda(T_C)\,d\lambda}, \tag{12}$$

where $\sigma T^4 = \int_0^\infty E_\lambda(T)d\lambda$, and $E_\lambda(T)$ is the planckian spectral irradiance function for a blackbody at temperature T.

Equation (12) can be written in the form

$$\rho_S(T_S, T_H, T_C) = \frac{\int_0^\infty \rho_\lambda(T_S)\tau_\lambda(T_S)\left[E_\lambda(T_H) - E_\lambda(T_C)\right]d\lambda}{\int_0^\infty \tau_\lambda(T_S)\left[E_\lambda(T_H) - E_\lambda(T_C)\right]d\lambda}. \tag{13}$$

This equation shows that the measured reflectance equals the integrated true spectral reflectance modified by the indicated weighting function. By definition, the true weighted reflectance of a surface at temperature T_S is given by

$$\rho_S(T_S) = \frac{\int_0^\infty \rho_\lambda(T_S)E_\lambda(T_S)\,d\lambda}{\int_0^\infty E_\lambda(T_S)\,d\lambda}. \tag{14}$$

The difference between the true reflectance and the measured reflectance is the measurement error, defined as

$$\delta\rho_S = \rho_S(T_S) - \rho_S(T_S, T_H, T_C), \tag{15}$$

or

$$\delta\rho_S = \frac{\int_0^\infty \rho_\lambda(T_S)E_\lambda(T_S)\,d\lambda}{\int_0^\infty E_\lambda(T_S)\,d\lambda} - \frac{\int_0^\infty \rho_\lambda(T_S)\tau_\lambda(T_S)\left[E_\lambda(T_H) - E_\lambda(T_C)\right]d\lambda}{\int_0^\infty \tau_\lambda(T_S)\left[E_\lambda(T_H) - E_\lambda(T_C)\right]d\lambda}. \tag{16}$$

A summation technique is used to evaluate the integrals of Equation (16). Equation (13) may be rewritten to give

$$\rho_S (T_S, T_H, T_C) = \sum_{n=1}^{m} \rho_{\Delta\lambda_n} (T_S)\, q_n ,$$

where

$$q_n = \frac{\tau_{\Delta\lambda_n} (T_S) \left[E_{\Delta\lambda_n} (T_H) - E_{\Delta\lambda_n} (T_C)\right]}{\sum_{n=1}^{m} \tau_{\Delta\lambda_n} (T_S) \left[E_{\Delta\lambda_n} (T_H) - E_{\Delta\lambda_n} (T_C)\right]} .$$

Here $\rho_{\Delta\lambda_n}$, $\tau_{\Delta\lambda}$, and $E_{\Delta\lambda}$ are defined over a wavelength band $\Delta\lambda$ rather than at a discrete wavelength λ. The summation is over the range $0 \leq \lambda \leq \infty$ and consequently, if m is large, each $\Delta\lambda_n$ will be small. Accuracy dictates the choice of $\Delta\lambda$, since the summation must follow the wavelength variation of each parameter in the integral. In a similar manner, Equation (14) may be written:

$$\rho_S (T_S) = \sum_{n=1}^{m} \rho_{\Delta\lambda_n} (T_S)\, p_n ,$$

where

$$p_n = E_{\Delta\lambda_n} / \sigma T_S^4 .$$

The measurement error, defined by Equation (16) in terms of the summations presented above, is

$$\delta \rho_S = \sum_{n=1}^{m} \rho_{\Delta\lambda_n} (T_S)\, p_n - \sum_{n=1}^{m} \rho_{\Delta\lambda_n} (T_S)\, q_n ,$$

or

$$\delta \rho_S = \sum_{n=1}^{m} \rho_{\Delta\lambda_n} (T_S) (p_n - q_n). \qquad (17)$$

Both p_n and q_n were calculated. Equations (16) and (17) show that the measurement error is contained within the difference between the two weighting functions, and that if they were equal there would be no error. The presence of the term $\tau_\lambda (T_S)$ is justified by the fact that it reduces the difference between the two weighting functions. In most cases the surface whose emittance is to be determined is at room temperature, so that $T_S \simeq$ 300K. The cavity temperatures are controlled at $T_H \simeq$ 315K and $T_C \simeq$ 305K. Because the difference between E_λ (300K) and $[E_\lambda$ (315K) - E_λ (305K)$]$ is largest at the shorter wavelengths, a selective filter such as black polyethelene can minimize this difference. The spectral transmittance $\tau_\lambda(T_S)$ of the black polyethelene compensating filter is given in Figure 1 for the wavelength range 2.5 to 40 microns (μm). $E_{\Delta\lambda}(T_S)$ and $[E_{\Delta\lambda}$ (315K) - $E_{\Delta\lambda}$ (305K)$]$ were determined from radiation tables (Reference 6). To simplify the calculations, only 20$\Delta\lambda_n$ (i.e., m = 20 in Equation 17) were chosen with particular emphasis given to the wavelength region that is important for a 300K blackbody. The resulting values of p_n, q_n and $(p_n - q_n)$ are given in Table 1.

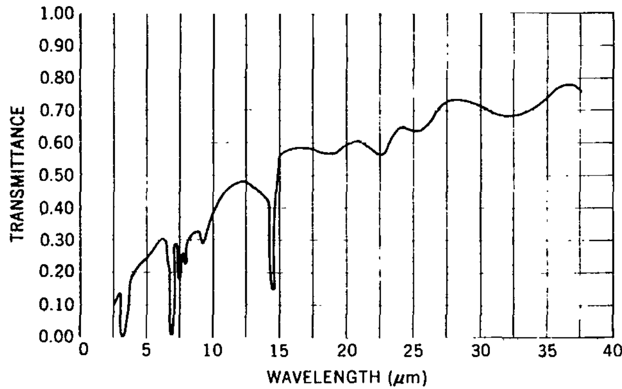

Figure 1. Infrared transmittance of black polyethelene filter.

Table 1

p_n, q_n and $p_n - q_n$ for $1 \leq n \leq 20$

n	Δλ (μm)	p_n	q_n	$p_n - q_n$
1	0-2	0.0000	0.0000	0.0000
2	2-4	0.0021	0.0026	-0.0005
3	4-6	0.0373	0.0665	-0.0292
4	6-8	0.1010	0.0942	0.0068
5	8-10	0.1332	0.1555	-0.0223
6	10-12	0.1304	0.1633	-0.0329
7	12-14	0.1124	0.1067	0.0057
8	14-16	0.0915	0.0777	0.0138
9	16-18	0.0727	0.0731	-0.0004
10	18-20	0.0575	0.0533	0.0042
11	20-22	0.0453	0.0398	0.0055
12	22-24	0.0360	0.0297	0.0063
13	24-26	0.0287	0.0250	0.0037
14	26-28	0.0232	0.0194	0.0038
15	28-30	0.0188	0.0158	0.0030
16	30-32	0.0153	0.0146	0.0007
17	32-34	0.0127	0.0069	0.0058
18	34-36	0.0106	0.0079	0.0027
19	36-38	0.0088	0.0082	0.0006
20	38-∞	0.0625	0.0398	0.0227
$\sum_{n=1}^{20}$		1.0000	1.0000	0.0000

The wavelength dependence of $(p_n - q_n)$, from which the non-grey error arises, is plotted in Figure 2. The effect of the compensating filter in reducing the difference between the weighting functions is shown by the dotted curve of Figure 2 which resulted from removing $\tau_{\Delta\lambda}(T_S)$ from the equations used to calculate p_n and q_n. Equation (17) and Figure 2 indicate that $\delta\rho_S$ is large for a sample having high reflectance at those wavelengths where $(p_n - q_n)$ is large. If the spectral reflectance is unknown beforehand, as is generally the case, a significant error can be recorded.

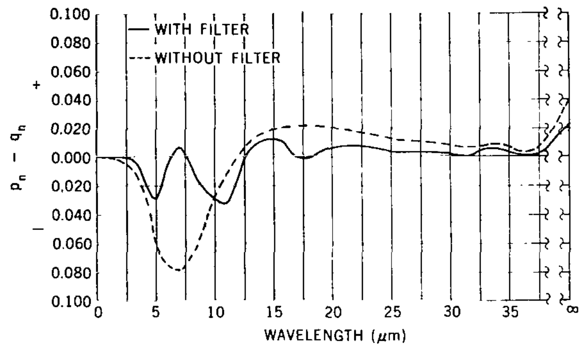

Figure 2. Effect of modifying filter on the spectral distribution of the difference between weighting functions.

Since p_n and q_n are normalized functions whose integrals are unity, the sum of their differences is zero, i.e.,

$$\sum_{n=1}^{m} (p_n - q_n) = 0.$$

Therefore, when the reflectance of a surface is invariant with wavelength, and $\rho_{\Delta\lambda_n}(T_S)$ is a constant in Equation (17), then $\delta\rho_S = 0$. This is true for a grey sample, and the conditions of Equation (11) apply.

RESULTS

The equations previously derived are in terms of reflectance, both spectral, $\rho_\lambda (T_s)$, and total, $\rho (T_s)$. The measurement error can be expressed in terms of emittance, using Kirchhoff's relation. Since

$$\epsilon_\lambda (T_s) = 1 - \rho_\lambda (T_s) - \tau_\lambda (T_s),$$

it follows that

$$\delta \epsilon_s (T_s) = - \delta \rho_s (T_s) \tag{18}$$

for an opaque surface.

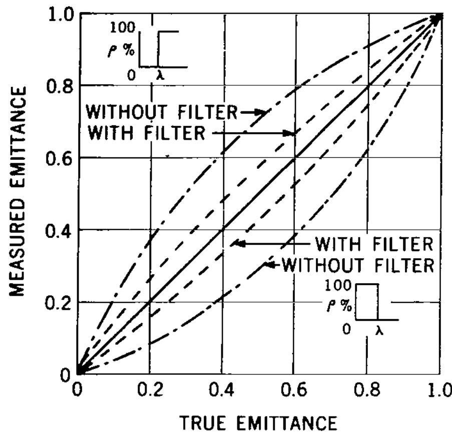

Figure 3. Effect of extreme spectral selectivity on the accuracy of measured total emittance.

Figure 3 presents the difference between the measured emittance and true emittance for two hypothetical cases of extreme spectral selectivity (demonstrated by the two inserted curves). Different emittances were obtained by varying the wavelength at which the step occurred in each reflectance spectrum. The error was calculated from Equations (17) and (18) with the aid of Table 1. It is evident from the figure that the influence of the modifying filter reduces the maximum non-grey error to a tolerable level even for these extreme cases.

To observe how the error appears in a more practical case, consider the reflectance curves shown in Figure 4. These reflectance curves demonstrate the thickness dependence of the infrared reflectance of vapor-deposited aluminum coated with various thicknesses of reactively-deposited silicon oxide. This material has been used as a thermal control surface on many satellites, and the results of a detailed study of its properties have been published (Reference 2). The data for Figure 4 were obtained from specular reflectance measurements performed on a Perkin-Elmer 621 spectrophotometer, and were used in conjunction with Equations (17) and (18) to calculate the magnitude of the non-grey error in the total emittance measurement. The calculated error is shown in Figure 5 for evaporated aluminum coated with various thicknesses of silicon oxide.

To compare the magnitude of the calculated error with the empirical error, spectral reflectance data for various samples were used with Equations (14) and (18) to obtain a "true emittance." Emittance values thus obtained are not subject to the non-grey error. Table 2 compares total emittance values measured directly, before and after correction for the non-grey error, with emittance values determined from weighted spectral reflectance measurements. The Alzak data shown in Table 2 were obtained from a Gier-Dunkle heated cavity reflectometer used with a Beckman IR-7 spectrophotometer to provide infrared spectral reflectances of diffuse surfaces. The Alzak coating is the result of an anodic deposition of aluminum oxide onto an aluminum surface (Reference 7). It employs the principle described earlier for silicon oxide-overcoated aluminum

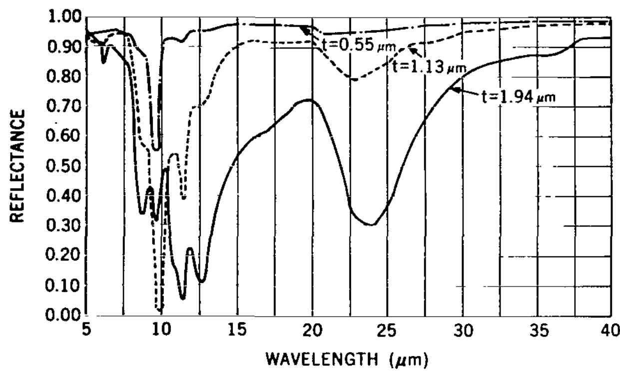

Figure 4. Infrared reflectance of aluminum coated with reactively deposited silicon oxide of various thicknesses.

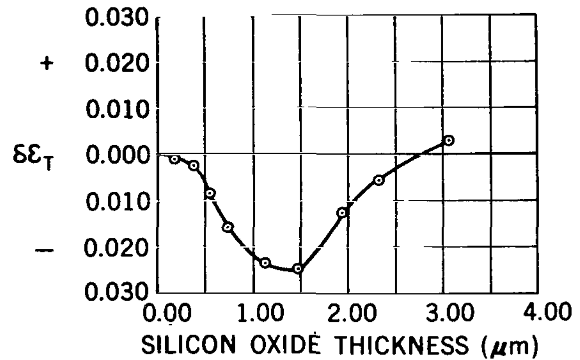

Figure 5. Calculated error in total emittance as a function of silicon oxide thickness.

Table 2

Near Normal Total Emittance* at 300 K

Sample	Oxide Thickness (μm)	Measured Directly		Emittance Deduced from Spectral Measurements
		Uncorrected Emittance	Corrected Emittance	
Evaporated Al coated with reactively deposited silicon oxide	0.17	0.013	0.011	0.013
	0.36	0.030	0.028	0.025
	1.11	0.245	0.221	0.222
	1.48	0.385	0.360	0.359
	1.94	0.455	0.443	0.445
	2.32	0.510	0.505	0.525
	3.06	0.555	0.558	0.583
Alzak	2.5	0.680	0.682	0.69
	5.0	0.73	0.75	0.78

*The third decimal place in the total emittance data is given only to illustrate the trend of the correction and is indicative of the reproducibility, but not the accuracy, of the measurements.

to give a thickness-dependent α/ϵ_T, and was used as the thermal control surface on the Orbiting Astronomical Observatory (OAO).

Table 2 shows that the difference between the spectrally determined and directly determined total emittances is reduced when the calculated correction for the non-grey error is applied to the total emittance data. The lack of perfect agreement indicates both the need for a better choice of weighting function in Equation (13) and the presence of other undefined instrumental errors. However, the data do empirically verify the presence of the non-grey error in the total emittance measurement.

CONCLUSION

These results show that it is not possible to eliminate the non-grey error using calibration techniques with currently available instrumentation when the dielectric film thickness varies in an unknown manner. Calibration would require knowing the infrared spectral reflectance of the measured surface, and this measurement would defeat from the start the requirement for a rapid determination of total emittance. In general, it is either impossible or impractical to measure the infrared spectral reflectance of coated satellite surfaces after assembly. Therefore, the only recourse is to calculate the magnitude of the non-grey error as it appears in a given type of instrument for a particular class of samples in order to correct the total emittance measurements accordingly.

A calibrated total emittance measuring device could still be used to monitor the uniformity of oxide thickness over a large area, since the emittance of the oxide coated surface is thickness dependent, but in this application it would compete with other available optical techniques. Of course, if the dielectric film thickness is initially known, the only need for an independent determination of emittance is to assure that the surface properties have not changed during assembly and storage. In this case, calibration is unnecessary.

Goddard Space Flight Center
National Aeronautics and Space Administration
Greenbelt, Maryland, January 28, 1971
124-09-26-16-51

REFERENCES

1. Drummeter, L. F., Jr., and Hass, G., "Solar Absorptance and Thermal Emittance of Evaporated Coatings," In: *Physics of Thin Films,* Vol 2, pp. 305-361, ed. by G. Hass and R. E. Thun, New York:Academic Press, 1964.

2. Bradford, A. P., Hass, G., Heaney, J. B. and Triolo, J. J., "Solar Absorptivity and Thermal Emissivity of Aluminum Coated With Silicon Oxide Films Prepared by Evaporation of Silicon Monoxide," *Applied Optics* 9(2):339-344, February 1970.

3. Edwards, D. K. and Nelson, K. E., "Maximum Error in Total Emissivity Measurements Due to Non-Grayness of Samples," *American Rocket Society Journal* 31(7):1021-1022, July 1961.

4. Nelson, K. E., Luedke, E. E., and Bevans, J. T., "A Device for the Rapid Measurement of Total Emittance," *J. Spacecraft* 3(5):758-760, May 1966.

5. Jakob, M., *Heat Transfer,* Vol. 1, p. 41, New York:John Wiley and Sons, 1949.

6. Stevenson, G. T., "Black-Body Radiation Functions," NAVWEPS Report 7621, U. S. Naval Ordnance Test Station, China Lake, California, May 1963.

7. Andrus, J. M. and Pettit, R., "Chemical Preparation of Aluminum for Chemical, Electrochemical Brightening and Anodic Coating," *Anodized Aluminum,* Special Technical Publication 388, pp. 1-20, American Society for Testing and Materials, Philadelphia, Pennsylvania, February 1965.

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