

NASA TECHNICAL NOTE



NASA TN D-7643

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**THE EFFECTS OF PARTICLE SIZE
ON THE OPTICAL PROPERTIES
AND SURFACE ROUGHNESS OF A
GLASS-BALLOON-FILLED BLACK PAINT**

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION • WASHINGTON, D. C. • MAY 1974

1. Report No. D-7643	2. Government Accession No.	3. Recipient's Catalog No.	
4. Title and Subtitle The Effects of Particle Size on the Optical Properties and Surface Roughness of a Glass-balloon-filled Black Paint.		5. Report Date MAY 1974	6. Performing Organization Code 760
		8. Performing Organization Report No. G-7432	
7. Author(s) Thomas Heslin, James Heaney, and Marvin Harper		10. Work Unit No. 039-23-01-01	
9. Performing Organization Name and Address Goddard Space Flight Center Greenbelt, Maryland 20771		11. Contract or Grant No.	
		13. Type of Report and Period Covered Technical Note	
12. Sponsoring Agency Name and Address National Aeronautics and Space Administration Washington, D. C. 20546		14. Sponsoring Agency Code	
15. Supplementary Notes			
16. Abstract The effects of particle size on the optical properties and surface roughness of a glass-balloon-filled, carbon-pigmented paint were studied in order to develop a diffuse-reflecting, low-total-reflectance, low-outgassing black paint. Particle sizes ranged between <20 microns and 74 microns. Surface roughness was found to increase with increasing particle size. Relative total reflectance at near-normal incidence (MgO standard) of the filled paints was less than for the unfilled paint between 230 nm and 1800 nm. Total absolute reflectance at 546 nm decreased with increasing particle size at grazing angles of incidence. Near-normal, total emittance was greater for the filled paints than for the unfilled paint. Specularity decreased with increasing particle size over the range studied.			
17. Key Words (Selected by Author(s)) Materials nonmetallic; Thermal control; Codings; Paint; Optical properties		18. Distribution Statement Unclassified—Unlimited CAT. 18	
19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages 9	22. Price* \$3.00

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

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THE EFFECTS OF PARTICLE SIZE ON THE OPTICAL PROPERTIES AND SURFACE ROUGHNESS OF A GLASS-BALLOON-FILLED BLACK PAINT

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INTRODUCTION

The earth-facing panel of the ITOS-D weather satellite (renamed NOAA-2 after launch) is covered with a multilayer aluminized Mylar and fiberglass-reinforced Kapton thermal insulation blanket. Since solar radiation is incident on the blanket at low grazing angles, it was necessary to cover the specularly reflecting Kapton outer layer of the blanket with a diffuse, low-total-reflectance coating to reduce error in the visible channel calibration of the very-high-resolution radiometer (VHRR) experiment. This error arose as a result of scattered radiation reflecting from the blanket onto the experiment calibration target. It was this requirement which initiated this study. In addition to this example on ITOS-D, recommendations regarding diffuse black coatings have been requested of materials engineers for other spacecraft. In each of these cases the coating was to be used in an optical system where there was a low-angle, first or second incidence line into a detector. Experimenters want a good black surface. For the most part, what makes a black surface good in the cases mentioned is low total reflectance, low specularity, mar resistance in handling, absence of flaking or dusting from the surface, mechanical flexibility, and low outgassing characteristics.

Nellessen of the 3M Company was one of the first to recognize the optical advantages of putting glass spheres in paints (Reference 1). More recently, work has been done with high-refractive-index glass microspheres in the size ranges 10 to 40 and 40 to 80 microns (Reference 2). However, the quantitative effect of particle size on certain optical properties has not been specifically studied. This paper phenomenologically addresses the effect of balloon particle size on specularity, total reflectance, and surface roughness.

PRELIMINARY INVESTIGATION

This work originated by combining the ease of application, good mar resistance, mechanical flexibility, and low-outgassing properties of a polyurethane vehicle with the good optical

effects due to glass spheres for a specific application. However, in conducting this preliminary investigation, information of a more general nature was obtained.

The base paint used in this investigation was a one-package, carbon black pigmented, flexible urethane composition.* It was selected because results of outgassing tests had shown this type of paint to be very low in outgassing. In an outgassing test (Reference 3) consisting of 24 hours in vacuum (1.333×10^{-4} N/m²) at 398 K with a 298 K condensing plate, the total weight loss for this paint from four different batches averaged 1.0 percent and the volatile condensable materials averaged 0.018 percent after an air cure of 14 days at 298 K.

In this investigation the base paint was filled with hollow glass microballoons.† These balloons are very light in weight compared to solid glass beads and are therefore more suitable for spacecraft applications.

Sample substrates were made of 6061 aluminum, and were 5.08 cm square by 0.159 cm thick. Fiberglass reinforced, aluminized Kapton was adhered to the substrates with double-stick tape. The aluminized side of the Kapton is the side which is reinforced with fiberglass, and this was the side that was painted. A 150-g batch of glass balloons was screened through a nest of sieves on a Rotap shaker. The nest was composed of W. S. Tyler Company sieves with opening sizes of 44, 37, and 20 microns. Glass balloons less than 20 microns and between 37 and 44 microns in diameter were used to make paint lots. One substrate was painted with the unfilled base paint. Paint lots for the other two samples were made using the following proportions:

Constituent	Parts by Weight
Base paint	1000
Toluene	200
Glass balloons	117

The balloons and toluene were mixed into the paint by hand stirring, and the paint was brushed onto the reinforced Kapton substrates with a paintbrush. Three coats of paint were applied. The samples were sent to RCA at Princeton, New Jersey, where preliminary goniophotometric measurements were made by shining nearly collimated energy onto the central portion of a painted test sample. The input radiance had a tungsten spectral distribution and was not filtered. The illumination on the sample was 3228 lumens/m². Reflected radiation was measured using a General Electric photometer. The results of these measurements are shown in Figure 1. These preliminary data indicate an inverse dependence of total reflectance and specularity on glass balloon size. These results prompted a more controlled investigation.

* A product of the Hughson Chemical Company.

† A product of the 3M Company.

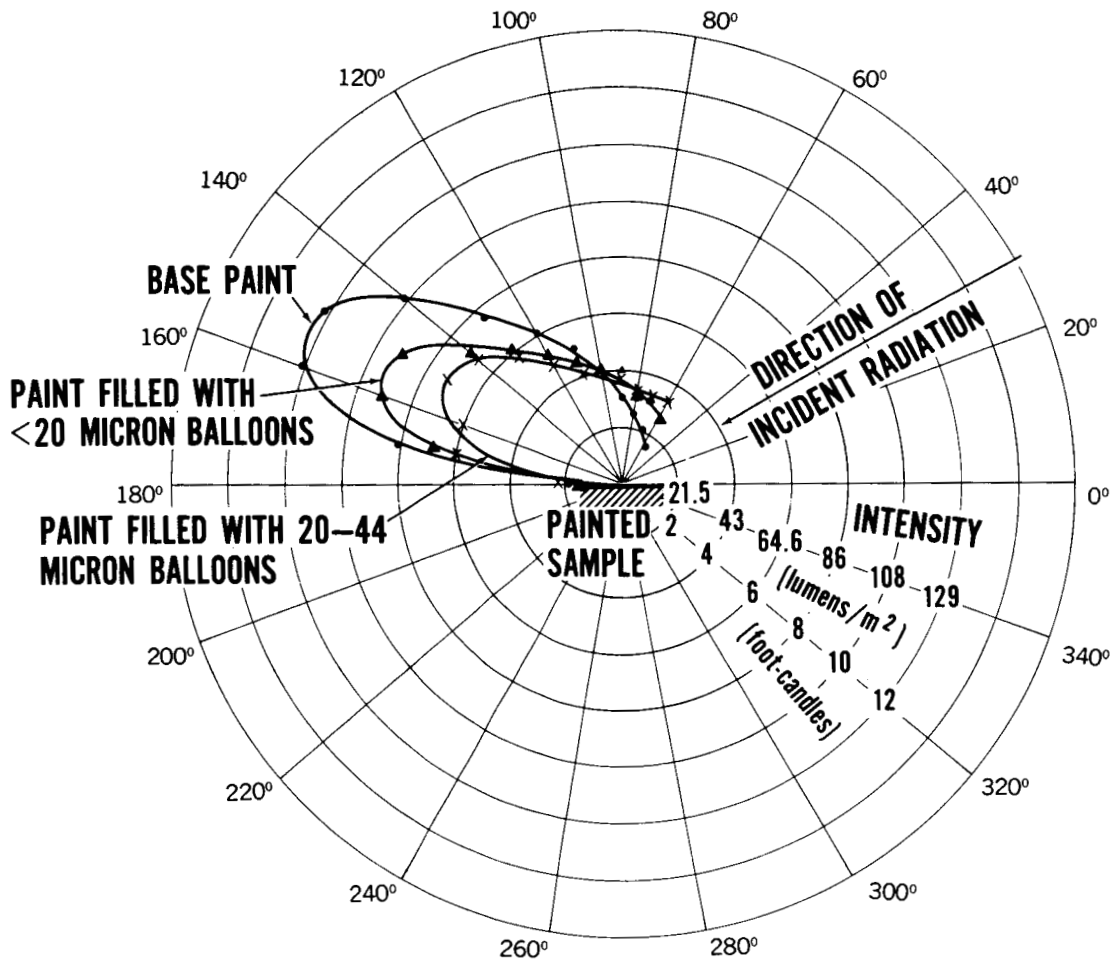


Figure 1. Preliminary Goniophotometer Measurements

FURTHER INVESTIGATION

More samples were made using similar 6061 aluminum substrates, but without the reinforced Kapton. This time the glass balloons were screened through a larger nest of sieves. The nest was composed of sieves with the following opening sizes in microns: 20, 37, 44, 53, 63, and 74. Glass balloon size fractions with diameters ranging between 20 and 37 microns, 44 and 53 microns, and 63 and 74 microns were used to make separate paint lots. In each case the filled paint was made up in the following proportions:

Constituent	Parts by Weight
Base paint	10
Toluene	5
Glass balloons	1

The paint was applied to the 5.08 cm-by-5.08 cm-by-0.159 cm squares of aluminum with an AU 70 Paasche airbrush, using an AF 3 nozzle at 342 kN/m² of N₂ and air dried. The paint thicknesses were measured with a micrometer. The paint thicknesses were, respectively, 0.127 mm, 0.152 mm, 0.254 mm, and 0.279 mm for the unfilled base paint, the paint filled with 20- to 37-micron balloons, the paint filled with 44- to 53-micron balloons, and the paint filled with 63- to 74-micron balloons.

OPTICAL AND PHYSICAL CHARACTERIZATION

The near-normal, total emittances of the painted samples were measured at 300 K with a Gier-Dunkle DB 100 portable infrared reflectometer (Reference 4). (The accuracy was ± 0.02 , the precision, ± 0.005 .) These data are shown below.

Description	Normal Emittance ϵ_n (300 K)
Base paint	0.915
Paint with 20- to 37- μ balloons	0.920
Paint with 44- to 53- μ balloons	0.923
Paint with 63- to 74- μ balloons	0.923

The total relative reflectances of the samples with a 5° angle of incidence were measured with a Beckman DK-1A recording spectrophotometer using a freshly smoked MgO reference. At near-normal incidence the error due to loss of radiation through the beam port is less for this measurement than for measurement of total absolute reflectance due to a difference in geometry of the two systems. The results of these relative reflectance measurements are shown in Figure 2.

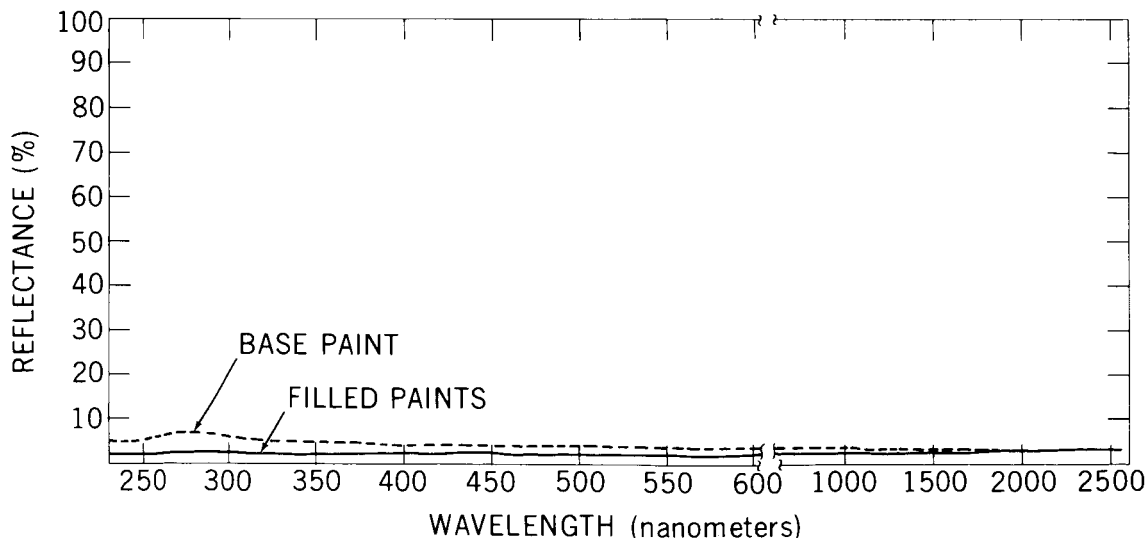


Figure 2. Total Reflectance at Normal Incidence (MgO Reference)

The total absolute reflectances at 546 nm at various angles of incidence were measured with a DK-2A recording spectrophotometer using an Edwards-type integrating sphere (Reference 5). The results of these measurements are shown in Table 1.

Table 1
Total Absolute Reflectance at 546 nm at Various Angles of Incidence

Description	Angle of Incidence				
	20°	40°	60°	70°	80°
Base paint	0.048	0.052	0.074	0.098	0.144
Paint with 20- to 37- μ balloons	0.040	0.048	0.068	0.090	0.130
Paint with 44- to 53- μ balloons	0.036	0.040	0.055	0.070	0.097
Paint with 63- to 74- μ balloons	0.037	0.040	0.053	0.064	0.084

The surface roughnesses of the samples were measured with a Talysurf-4 profilometer. The surface profiles are shown in Figure 3.

Goniophotometric measurements were performed at GSFC at a single wavelength (546 nm). These measurements were made at an angle of incidence of 80°. The directional relationship between incident beam, sample plane, and detector position is shown in Figure 4. All measurements were made in the plane of incidence, $\phi = 0$. The detector collection aperture was 1.27 cm in diameter and 20.3 cm from the point of incidence on the sample, and it could be rotated in the $\phi = 0^\circ$ plane to measure the radiant intensity at different angles of reflection. At a given angle the detector measured the fraction of incident radiation which was reflected into the solid angle defined by the aperture of the detector. This quantity is designated $R(\theta_r)$. The wavelength of incident radiation, and the plane and angle of incidence are all constant, as is the distance of the detector from the center of the area of incidence.

The quantity $R(\theta_r)$ is plotted versus angle of reflectance, θ_r , in Figure 5. Table 2 gives a tabulation of the specular peak values of $R(\theta_r)$ and also

$$\int_{\theta = -90^\circ}^{\theta = -10^\circ} R(\theta_r) d\theta_r.$$

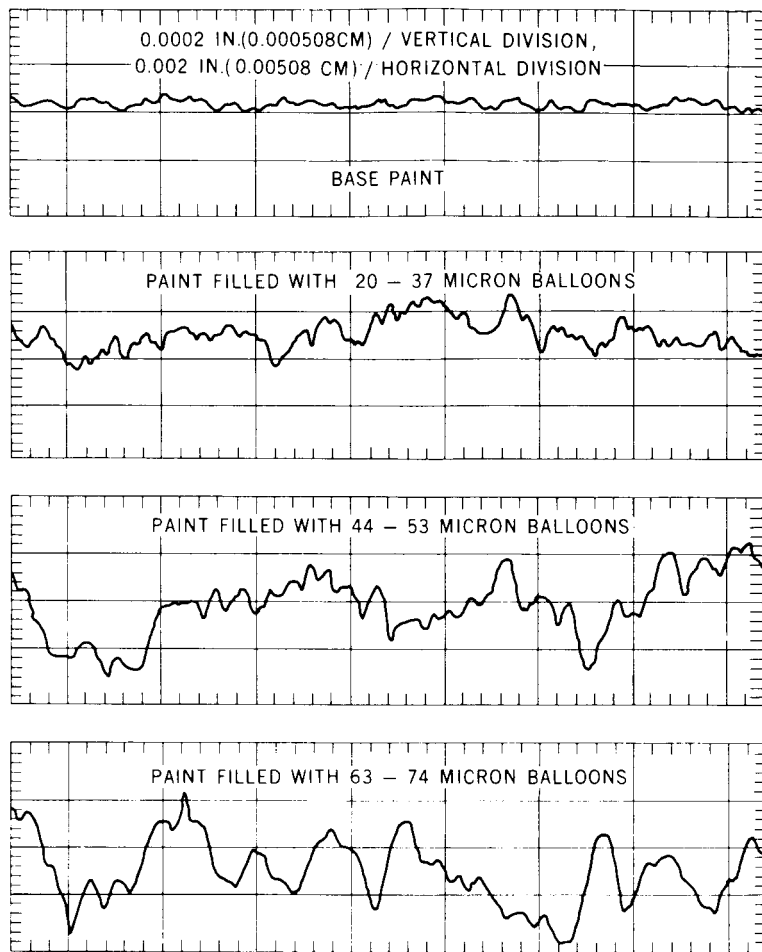


Figure 3. Surface Roughness Profiles

Table 2

Specular Peak and Integral Values of $R(\theta_r)$

Description	$R(\theta_r)$	$\int_{\theta = -90^\circ}^{\theta = -10^\circ} R(\theta_r) d\theta_r$
Base Paint	2.83×10^{-3}	2.34×10^{-2}
Paint with 20- to 37- μ balloons	4.75×10^{-4}	6.0×10^{-3}
Paint with 44- to 53- μ balloons	2.7×10^{-4}	3.9×10^{-3}
Paint with 63- to 74- μ balloons	2.1×10^{-4}	3.1×10^{-3}

CONCLUSIONS

Over the glass-balloon size range studied (20 to 74 microns), surface roughness increased with increasing balloon size as expected. The total reflectance of the filled paints at near-normal incidence was less than for unfilled paint between 230 to 1800 nm. The total absolute reflectance at 546 nm decreased with increasing balloon size at grazing angles of incidence. Near-normal total emittance was greater for the filled paints than for the unfilled paint.

The most noteworthy result of the study was that specularity decreased with increasing balloon size, over the size range studied, at 546 nm. This confirms the possibility of tailoring a reflective surface to fit a particular design requirement by selecting a given size of glass balloons. It also points the way for future study.

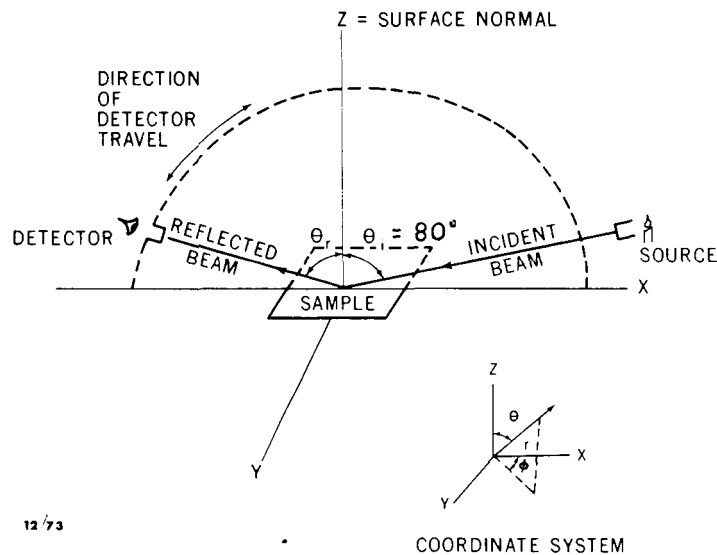


Figure 4. Source-Detector Directional Relationships

FUTURE STUDY

The balloon size range studied should be extended, especially into the range of the wavelength of the incident light. Goniophotometric measurements should be made at wavelengths in the ultraviolet and the infrared. Emissivity measurements should be made at cryogenic temperatures to augment the present room temperature data, since many spacecraft applications are at low temperatures.

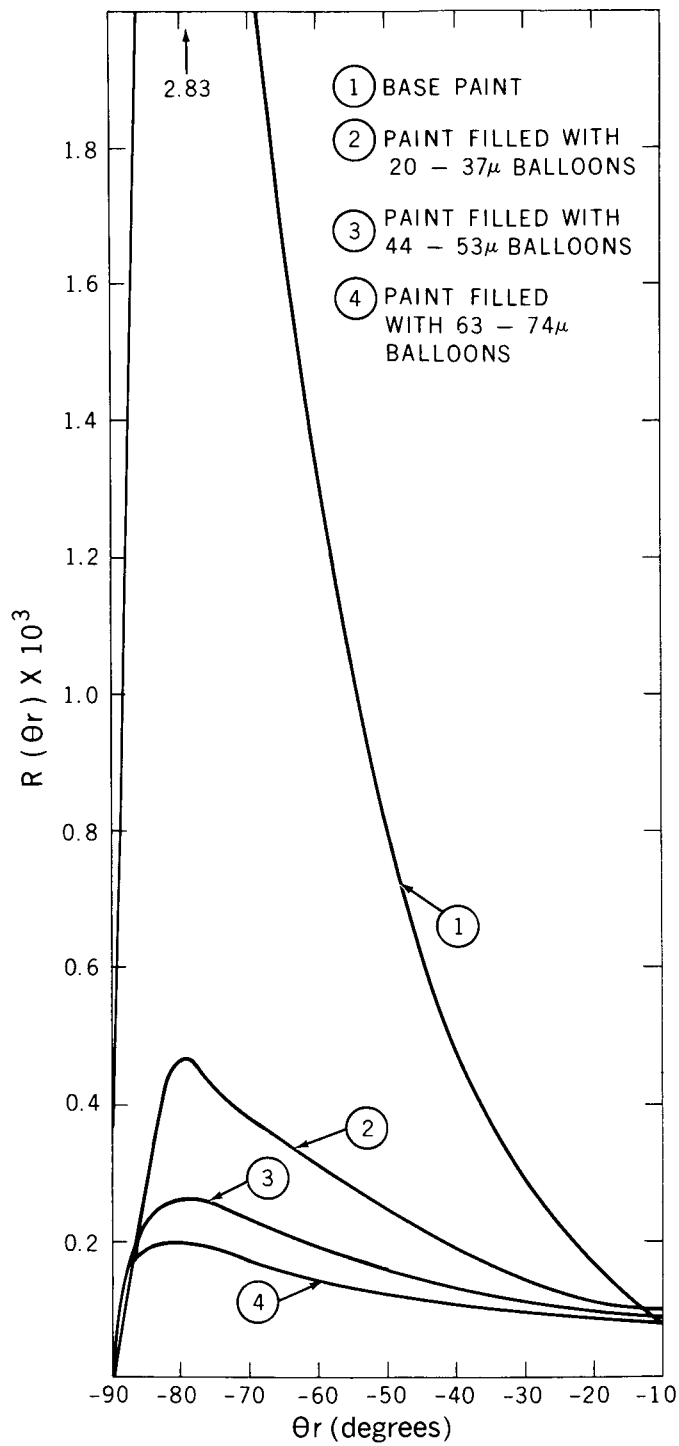


Figure 5. Goniophotometer Measurements

ACKNOWLEDGMENTS

The apparatus used to perform the goniophotometric measurements at GSFC was designed and constructed by Mr. Mitchell Finkel. The authors would like to thank him for his advice and help in performing these measurements. We thank Mr. Ronald Hunkeler for preparing and spraying paint samples and making reflectance measurements.

Goddard Space Flight Center
National Aeronautics and Space Administration
Greenbelt, Maryland June 1973
039-23-01-01-51

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