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Preflight Characterization of SAMMES II Specimens

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Brent Hickel

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13. ABSTRACT (*Maximum 200 words*)

The preflight characterization of flight specimens for the Space Active Modular Materials Experiment (SAMMES) II mission has been completed by The Aerospace Corporation and the Illinois Institute of Technology Research Institute (IITRI). The specimens consisted of calorimeter substrates coated with the following IITRI paints: Z-93P, S13GP/LO-1, YB-71, and MH21S/LO. Four samples were prepared, each coated with a different paint. One or more of each type of sample were subjected to all measurements. These measurements included mass, density, thickness, solar absorptance, normal emittance, hemispherical emittance, and traceability. Comparisons were made between measurements done at IITRI, Aerospace, and McDonnell Douglas Astronautics for both solar absorptance and thermal emittance.

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1. Introduction

Preflight characterization has been completed of the specimens for the Space Active Modular Materials Experiment (SAMMES) II mission, scheduled to fly with the Space Technology Research Vehicle 2 module on the Space Test Program TSX-5 spacecraft in early 1998. As part of this characterization, the solar absorptance, hemispherical emittance, normal emittance, mass, density, and thickness were measured for the samples provided by the Illinois Institute of Technology Research Institute (IITRI). These samples consisted of aluminum calorimeter substrates coated with each of the following paints: Z-93P, S13GP/LO-1, YB-71, and MH21S/LO. Measurements were performed by IITRI, The Aerospace Corporation, and McDonnell Douglas Astronautics. This report documents the preflight characterization of the material properties of the samples, including the processing and traceability data provided by IITRI.[1]

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[1] T. J. Curtis, M Deshpande, W. Sabato, and Y. Harada, *Preflight Solar Absorptance and Total Emittance of Thermal Control Coatings for SAMMES Flight Experiment*, documentation accompanying Aerospace Purchase Order No. 78733-E to IITRI (16 October 1995).

2. Background

SAMMES was created under funding from the Ballistic Missile Defense Organization (BMDO) Materials and Structures program. The purpose of SAMMES is to provide affordable and frequent access to space for on-orbit, time-dependent measurement of material properties of engineering interest. One of the capabilities of the SAMMES payload is the direct measurement of the solar absorptance and hemispherical emittance of materials using calorimetric techniques. This capability allows direct measurement of the real-time degradation of spacecraft thermal control coatings on orbit and provides complementary data for ground-based testing of such materials.

The SAMMES I payload was lost with the launch abort of the STEP-3 mission due to failure of the Orbital Sciences Corporation Pegasus launch vehicle on 22 June 1995. The SAMMES I payload contained specimens of the three recently reformulated IITRI white thermal control coatings: Z-93P, S13GP/LO-1, and YB-71P. Samples of these coatings were included to obtain on-orbit data on their performance, as part of the U. S. Air Force Space and Missile Systems Center (SMC)/Chief Engineer's white thermal paint requalification program. This program was the final phase of the complete requalification test program designed to ascertain the success of the reformulation of the coatings. In addition, the program was designed to provide data to assure users that the new coatings performed as well as the older, and now unavailable, coatings.

Reformulation of these three coatings was required due to the recent loss of a key ingredient in the three coatings: Sylvania PS-7 (potassium silicate). With the discontinued production of the ingredient by the vendor, a new source of this chemical, or a replacement material, had to be found and incorporated into the manufacture of these coatings. IITRI was contracted by the Air Force to perform this work since they were the developer and manufacturer of the original coatings. The work was funded by the U. S. Air Force SMC Office of the Chief Engineer (SMC/SD) through a contract from Wright Laboratory/Materials Directorate.

With the loss of the SAMMES I payload, the immediate opportunity to obtain flight data for the three IITRI coatings was also lost. The SAMMES II mission is scheduled to fly with the Space Technology Research Vehicle 2 module on the Space Test Program TSX-5 spacecraft in early 1998 in a 400 x 1880 km orbit. This mission has reopened the window of opportunity to obtain the needed flight data. The SAMMES instrument suite currently under construction can carry 13 calorimeters. The Aerospace Corporation Mechanics and Materials Technology Center (MMTC) conducted a workshop to solicit candidate materials for these calorimeters. This workshop was attended by Aerospace, SMC, Phillips Laboratory (PL), Jet Propulsion Laboratory (JPL), and contractors. A list of 40 candidate materials was prioritized against the perceived needs of SMC, BMDO, and IMO programs. Included in the materials selected were four IITRI coatings. Two of these coatings were the reformulated coatings, Z-93P and S13GP/LO-1. The other two coatings consisted of a black coating, MH21S/LO, and the original white coating, YB-71. The newer, reformulated version of this white coating, YB-71P, was not included due to problems encountered with this material during the requalification program.

3. Processing and Activities Traceability

Sixteen pairs of calorimeter cups [Serial Numbers (SN) 101–116] and disks (SN 001–016) were coated by the Advanced Materials and Coatings Laboratory at IITRI under Purchase Order No. 78733-E from The Aerospace Corporation to IITRI. The engineering drawing of a calorimeter cup and disk with the designation of the surfaces coated is shown in Figure 1. The cups and disks were received from the SAMMES contractor, RSI, Inc.

3.1 Surface Preparation

All pairs of cups and disks were abraded using 150 grit SiC paper and cleaned with research grade ethanol. After being dried, they were weighed to the nearest 0.1 milligram. Masking was accomplished using 3M No. 324 tape. Four pairs of calorimeter cups and disks were then mounted on individual boards, along with 20 1-in.-diam Al 6061 disks as companion witness samples. The witness samples had been cleaned and abraded in a manner identical to that for the cups and disks. The four boards prepared were designated HW, HX, HY, and HZ and used for the deposition activities of the four respective coatings that were to be applied.

Table 1 shows the organization of the deposition activity, including the IITRI Batch Card No. and date of specimen coating. The substrate preparation activities are covered under IITRI Batch Card No. U-345A, dated 27 September 1995.

3.2 Weighing

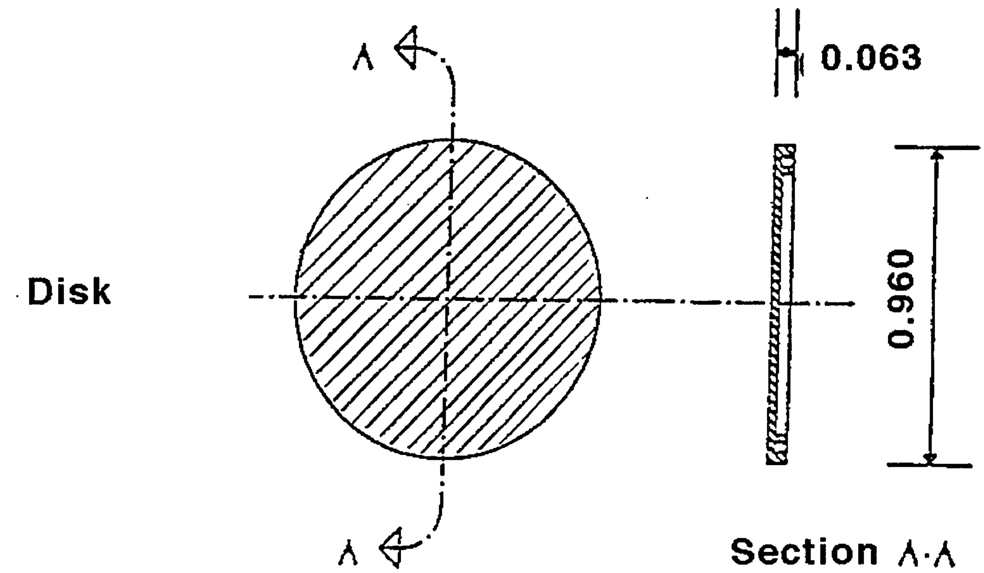
Each calorimeter cup and disk were weighed on a Mettler balance to the nearest 0.1 mg. The data are given in Tables 2 and 3.

3.3 Masking

All cups and disks were masked with 3M No. 324 tape to cover surfaces that were not to be coated. This tape meets all of the requirements set forth for each coating.

Table 1. Organization of Deposition Activity

Board No.	Disk No.	Cup No.	Witness Sample No.	Thermal Control Material System	Deposition Batch No./Date
HW	SN001	SN101	HW-1	YB-71	U-348
	SN002	SN102	to		9/28/95
	SN003	SN103	HW-20		
	SN004	SN104			
HX	SN005	SN105	HX-1	Z-93P	U-347
	SN006	SN106	to		9/28/95
	SN007	SN107	HX-20		
	SN008	SN108			
HY	SN009	SN109	HY-1	S13GP/LO-1	U-348
	SN010	SN110	to		9/28/95
	SN011	SN111	HW-20		
	SN012	SN112			
HZ	SN013	SN113	HZ-1	MH21S/LO	U-396
	SN014	SN114	to		10/18/95
	SN015	SN115	HZ-20		
	SN016	SN116			



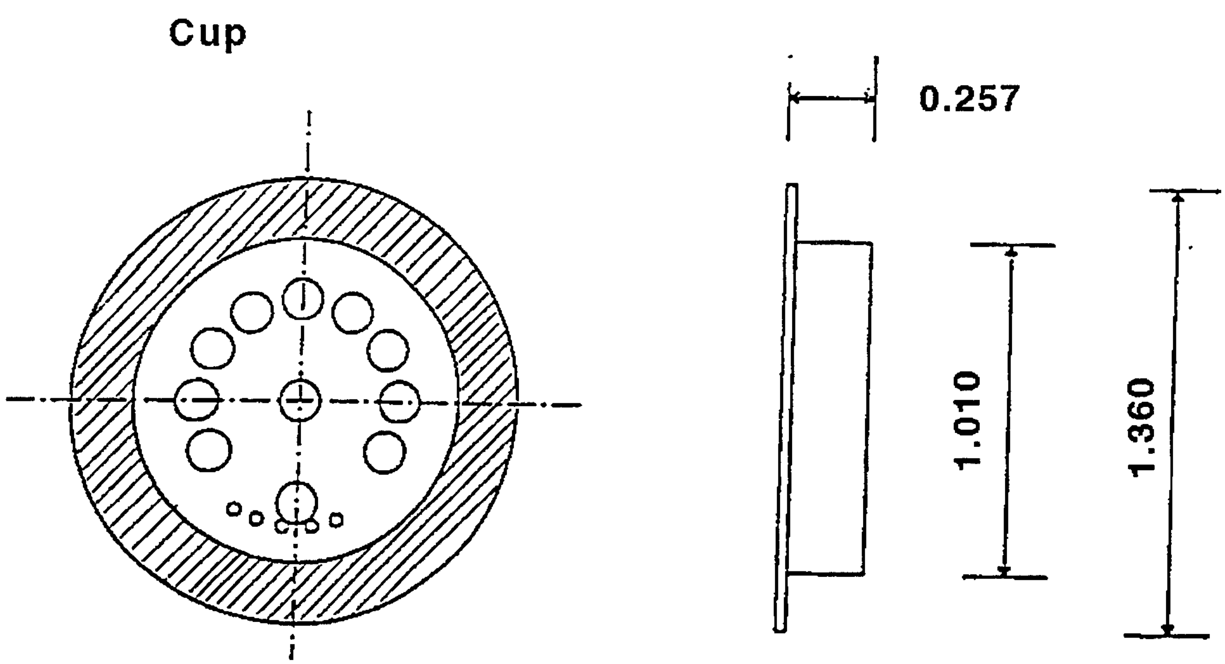


Figure 1. SAMMES calorimeter disks and cups. (Shaded area indicates where coating was applied.)

Table 2. Physical Data on SAMMES Disk Samples

Coating	Sample I. D.	Substrate Weight (g)	Coated Sample Weight (g)	Coating Weight (g)	Thickness (mils)	Density (g/cc)
YB-71	SN001	1.1266	1.4003	0.2737	8.40	2.75
	SN002	1.1285	1.3983	0.2698	8.30	2.74
	SN003	1.1283	1.3975	0.2692	8.60	2.64
	SN004	1.1281	1.3843	0.2562	8.30	2.60
Z-93P	SN005	1.1214	1.2186	0.0972	5.30	1.55
	SN006	1.1290	1.2074	0.0784	4.40	1.50
	SN007	1.1250	1.2094	0.0844	5.00	1.42
	SN008	1.1262	1.2025	0.0763	4.30	1.50
S13GP/LO-1	SN009	1.1257	1.4042	0.2785	10.10	2.32
	SN010	1.1290	1.4072	0.2782	9.50	2.47
	SN011	1.1261	1.3988	0.2727	9.80	2.35
	SN012	1.1233	1.3890	0.2657	8.00	2.80
MH21S/LO	SN013	1.1305	1.1833	0.0528	3.20	1.52
	SN014	1.1201	1.1845	0.0644	3.40	1.60
	SN015	1.1221	1.1775	0.0554	3.10	1.51
	SN016	1.1266	1.1879	0.0613	3.50	1.48

Table 3. Physical Data on SAMMES Cup Samples

Coating	Sample I. D.	Substrate Weight (g)	Coated Sample Weight (g)	Coating Weight (g)	Thickness (mils)	Density (g/cc)
YB-71	SN101	1.9679	2.1939	0.226	9.30	2.28
	SN102	1.8968	2.1716	0.2748	10.90	2.36
	SN103	1.9425	2.1797	0.2372	9.00	2.47
	SN104	1.8998	2.1461	0.2463	10.40	2.21
Z-93P	SN105	1.9425	2.0191	0.0766	5.10	1.41
	SN106	1.9354	2.0355	0.1001	7.00	1.39
	SN107	1.9353	2.0089	0.0736	4.50	1.53
	SN108	1.9211	2.0071	0.086	5.80	1.39
S13GP/LO-1	SN109	1.9322	2.2389	0.3067	11.80	2.43
	SN110	1.9219	2.2114	0.2895	12.00	2.25
	SN111	1.9253	2.2516	0.3263	11.80	2.59
	SN112	1.9588	2.2270	0.2682	12.00	2.32
MH21S/LO	SN113	1.9281	1.9785	0.0504	3.60	1.35
	SN114	1.9299	1.9861	0.0562	3.50	1.49
	SN115	1.9150	1.9722	0.0572	4.20	1.28
	SN116	1.8719	1.9325	0.0606	4.60	1.23

3.4 Deposition and Curing

3.4.1 Coating YB-71

The YB-71 processing was carried out per the best practices defined in report NASA-31906/IITRI-M06020-62, and meets process specifications NASA-MSFC-PROC-1484A and IITRI-MD-C08089-SP11.

YB-71 was deposited on Board No. HW and listed on Batch Card No. U-348, dated 28 September 1995. The details are presented below.

Materials Used

Pigment:	Zinc orthotitanate, Lot No. ZOT # 98790
Amount used:	455.0 g
Binder:	PS-7, Sylvania, Lot No. 5381-B2
Amount used:	183.1 g
D. I. H_2O:	18 MΩ, Millipore, Inc.
Amount used:	45.5 cc

Pigment to Binder Ratio

7.1

All materials were put into a jar mill used exclusively for YB-71 formulation and milled for 4 h.

Substrate Priming

Samples HW-1–HW-20, cups SN101–104, and disks SN001–004 were primed by rubbing the substrate with Z-93P (Batch T-232) and allowing it to air dry. The YB-71 deposition was carried out 4 h after priming was completed.

Deposition Parameters

Temperature = Room temperature
Humidity ≈ 74% RH (> 50% required)

Spraying of YB-71 was carried out to a wet thickness of 14 to 16 mils. The board HW was then transferred to the humidity chamber for curing.

Cure Parameters

Initial Cure:
Temperature = Room temperature
Humidity = 50% RH
Time = 16–18 h (overnight)

Final Cure:
Temperature = Room Temperature
Humidity = Ambient
Time = 14 days

Demasking

Calorimeter cups and disks were demasked on the fifth day after deposition for ease of demasking. No major touch-ups of the coating were required.

Testing

After complete cure, solar absorptance and total normal emittance were measured, along with coating weight and thickness. Density of the coating was determined from the thickness and weight. All testing results are presented in the sections on physical and optical properties.

3.4.2 Coating Z-93P

The Z-93P processing was carried out per the best practices defined in report AFML-TR-94-4126/IITRI-C06756, and meets process specification IITRI-MD-C08089-SP10. The deposition activities for Z-93P on board HX are listed on Batch Card No. U-347, dated 28 September 1995. The details are presented below.

Materials Used

Pigment:	ZnO (SP-500), Lot No. 004054
Supplier:	Zinc Corporation of America
Calcination Batch:	T-182, dated 8 August 1994
Calcination Temperature:	625°F
Calcination Time:	24 h
Amount used:	300.0 g
Binder:	Kasil 2130, Lot No. C061894
Supplier:	P. Q. Corp.
Amount used:	174 cc
D. I. H_2O:	18 MΩ, Millipore, Inc.
Amount used:	201 cc

Pigment to Binder Ratio

4.3

All materials were put into a jar mill used exclusively for Z-93P formulation and milled for 30 min.

Substrate Priming

Samples HX-1–HX-20, cups SN105–108, and disks SN005–008 were primed by rubbing the substrate with Z-93P (Batch T-232) prior to deposition of the Z-93P coating. The deposition was carried out 4 h after priming was completed.

Deposition Parameters

Temperature = Room temperature
Humidity ≈ 74% RH (>50% required)

Spray deposition of Z-93P was carried out to a wet thickness of 6 to 8 mils. The board HX was then transferred to the humidity chamber for curing.

Cure Parameters

Initial Cure:
- Temperature = Room temperature
- Humidity = 50% RH
- Time = 16–18 h (overnight)

Final Cure:
- Temperature = Room temperature
- Humidity = Ambient
- Time = 14 days

Demasking

Calorimeter cups and disks were demasked on the fifth day after deposition for ease of demasking. No major touch-ups of the coating were required.

Testing

After complete cure, solar absorptance and total normal emittance were measured, along with coating weight and thickness. Density of the coating was determined from the thickness and weight. All testing results are presented in the sections on physical and optical properties.

3.43 Coating S13GP/LO-1

The S13GP/LO-1 processing was carried out per the best practices defined in report AFML-TR-94-4126/ IITRI-C06756, and meets process specification IITRI-MD-C06788-SP1. Cups and disks were processed per specification IITRI-MD-C06788-SP2 and NASA-MSFC-PROC-1384A. The deposition activities for S13GP/LO-1 on board HY are listed on Batch Card No. U-349, dated 28 September 1995. The details are presented below.

Material Used

Pigment:	Micro-encapsulated ZnO (SP-500)
Pigment Batch:	U-299, dated 30 August 1995
Binder:	MHS/LO, Stripped polydimethyl siloxane (SWS-884)
Supplier:	Wacker Silicones, Inc. (vacuum stripped at IITRI)
Binder Batch:	U-232, dated 16 June 1995

Pigment to Binder Ratio

2.1, Paint Batch U-310, dated 1 September 1995

Substrate Priming

Samples HY-1–HY-20, cups SN109–112, and disks SN009–012 were primed after grit abrading (3M 150 grit SiC paper) and cleaning with research grade ethanol. The primer used was SS044 primer solution, Lot No. U-233, dated 16 June 1995. Priming was performed under dry conditions. The primed samples on the HY board were then coated with thinned, catalyzed, sprayable paint, in a dry spray area (humidity < 50%) after 0.5 h, and within 2 h, after priming.

Deposition Parameters

Temperature:	Room temperature (72°F)
Humidity:	Acrid (<50% RH)
Mixing:	Per IITRI-MD-CO6788-SP2

Coating thickness of a minimum of 8 mils is required, per the optical property requirements of the material specification. The initial cured thickness was 5–6 mils. Additional material of Batch U-310, dated 1 September 1995, was catalyzed, per specification, and sprayed onto the samples to achieve the required thickness.

Cure Parameters

Initial Cure:
- Temperature = Room temperature
- Humidity = Dry (<50% RH)
- Time = 16–18 h (overnight)

Final Cure:
- Temperature = Room temperature
- Humidity = Ambient
- Time = 7 days

Demasking

Calorimeter cups and disks were demasked on the seventh day after deposition for ease of demasking. No major touch-ups of the coating were required.

Testing

After complete cure, solar absorptance and total normal emittance were measured, along with coating weight and thickness. Density of the coating was determined from the thickness and weight. All testing results are presented in the sections on physical and optical properties.

3.4.4 Coating MH21S/LO

The MH21S/LO processing was carried out per the best practices defined in report IITRI-C06678, and meets process specification IITRI-MD-C08089-SP15. Cups and disks were processed per specification IITRI-MD-C08089-SP12. The deposition activities for MH21S/LO on board HZ are listed on Batch Card No. U-396, dated 18 October 1995. The details are presented below.

Materials Used

Pigment:	Black glass
Pigment Batch:	B. G. 69, T-156, dated 13 July 1994
	B. G. 73, T-343, dated 13 December 1994
	B. G. 76, T-351, dated 27 December 1994
Binder:	MHS/LO, stripped polydimethyl siloxane (SWS-884)
Supplier:	Wacker Silicones, Inc. (vacuum stripped at IITRI)
Binder Batch:	U-238, dated 21 June 1995

Pigment to Binder Ratio

2.0, Batch No. U-360, dated 14 October 1995

Substrate Priming

Samples HZ-1–HZ-20, cups SN113–116, and disks SN013–016 were primed after grit abrading (3M 150 grit SiC paper) and cleaning with research grade ethanol. The primer used was SS044 primer solution, Lot No. U-233, dated 16 June 1995. Priming was performed under dry conditions. The primed samples on the HY board were then coated with thinned, catalyzed, sprayable paint, in a dry spray area (humidity < 50%) after 0.5 h, and within 2 h, after priming.

Deposition Parameters

Temperature:	Room temperature (72°F)
Humidity:	Arid (<50% RH)
Mixing:	Per IITRI-MD-C-8089-SP15

Coating thickness of 3 to 4 mils is required. This translates to 4 to 6 passes at 30 psig setting per experience. The thickness was measured the next day after deposition to verify the thickness. No additional paint application was necessary.

Cure Parameters

Initial Cure:

Temperature = Room temperature
Humidity = Dry (<50% RH)
Time = 16–18 h (overnight)

Final Cure:

Temperature = Room temperature
Humidity = Ambient
Time = 7 days

Demasking

Calorimeter cups and disks were demasked on the seventh day after deposition for ease of demasking. No major touch-ups of the coating were required.

Testing

After complete cure, solar absorptance and total normal emittance were measured, along with coating weight and thickness. Density of the coating was determined from the thickness and weight. All results are presented in the following sections on physical and optical properties.

4. Physical Properties

As previously discussed, the substrate cups and disks were weighed to the nearest 0.1 milligram after preparation and drying. After the samples were coated, and the paints were allowed to properly cure for the specified times, the samples were reweighed in the same manner. The thickness of the coatings was determined using a Elcometer 300 thickness gauge. Tables 2 and 3 (section 3, page 7) contain the weight and thickness data for the disks and cups, respectively. The density of each coating is also calculated and included in the tables.

5. Optical Properties

5.1 IITRI Measurements

5.1.1 Solar Absorptance

The diffuse spectral reflectance of the disk specimens was measured at IITRI using a Perkin-Elmer Lambda-19 UV/VIS/NIR spectrometer equipped with a Perkin-Elmer $BaSO_4$ coated integrating sphere attachment. The spectrometer settings were 480 nm/min scan rate, 2 mm slit width, and 1 s response; the scan range was 250–2500 nm. A Labsphere, Inc., Spectralon reflectance standard was used as a secondary calibration standard. This secondary standard was calibrated against a NIST 2019d white tile diffuse reflectance standard. The appendix to this report contains the reflectance curves for the SAMMES disk specimens. These curves were corrected with respect to the NIST standard. Solar absorptance was calculated from the reflectance data per ASTM standards E903 and E490[2,3] using the selected ordinate method and employing a 49 point calculation. The results are presented in Table 4.

5.1.2 Total Normal Emittance

The total normal emittance of each disk sample was measured at IITRI using a Gier-Dunkle DB-100. The DB-100 is an infrared (IR) reflectometer that is used for measurement of the normal emittance of samples. The instrument consists of a case containing the electronics, readout, and controls, and an inspection head that interrogates the surface or specimen of interest. The inspection head is cylindrical and contains two semi-cylindrical cavities. One of the cavities is heated, and the other is at room temperature. Thus, a difference is maintained in the temperature of the two cavities. The two cavities rotate at 13 Hz and alternately interrogate the sample. A vacuum thermocouple detector receives the emitted thermal energy from the specimen. The electronics amplify and process the signal and convert it to a reading from 0 to 1.00 for total normal emittance. Since the sample is viewed only in a normal orientation, the emittance value is not the total hemispherical emittance that is required for thermal models. Conversion of this normal emittance to hemispherical emittance can be done using established relationships for flat surfaces.[4] The values for the total normal emittance are presented in Table 4.

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[2] ASTM E903, *Standard Test Method for Solar Absorptance, Reflectance and Transmittance of Materials Using Integrating Spheres.*

[3] ASTM E490, *Standard Solar Constant and Air Mass Zero Solar Spectral Irradiance Tables.*

[4] M. Jakob, *Heat Transfer*, Vol. I, John Wiley and Sons, Inc., New York, pp. 44–52.

Table 4. IITRI Solar Absorptance and Normal Emittance of Disks

Coating	Sample I. D.	Solar Absorptance α_s	Total Normal Emittance ε_n
YB-71	SN001	0.11	0.89
	SN002	0.11	0.89
	SN003	0.11	0.89
	SN004	0.11	0.89
Z-93P	SN005	0.12	0.92
	SN006	0.13	0.92
	SN007	0.13	0.92
	SN008	0.13	0.92
S13GP/LO-1	SN009	0.16	0.90
	SN010	0.16	0.90
	SN011	0.16	0.90
	SN012	0.17	0.90
MH21S/LO	SN013	0.97	0.90
	SN014	0.97	0.91
	SN015	0.97	0.90
	SN016	0.97	0.90

5.2 The Aerospace Corporation Measurements

5.2.1 Solar Absorptance

The Aerospace Corporation also measured the diffuse spectral reflectance of the disk specimens. The measurements were made using a Perkin-Elmer Lambda-9 UV-VIS-NIR spectrometer equipped with a 6 in. Labsphere, Inc., Spectralon coated integrating sphere. This sphere is larger and somewhat more accurate than the smaller Perkin-Elmer sphere. The spectrometer settings were 480 nm/min scan rate, 2 nm slit width, and 1 s response; the scan range was 250–2500 nm. In this set of measurements, a Teflon mask was used to protect the surface and edges of the sample as it was held against the sphere.

The reflectance spectra were background corrected and referenced to a NIST 2019d white tile diffuse reflectance standard. This procedure references the sample spectrum to a NIST perfect diffuser rather than to the Spectralon integrating sphere coating. Correction factors are calculated and applied to the sample spectrum from the measured NIST standard. The accuracy of the reflectance measurements are ± 2%. The reflectance curves are included in the appendix to this report.

The calculation of the solar absorptance was made from the reflectance spectrum (assuming that the samples are opaque) over the range of measurement using the trapezoidal rule to approximate the integral in Eq. (1) below:

$$\alpha_s(\lambda_1,\lambda_2) = \frac{\int_{\lambda_1}^{\lambda_2} \mathbf{S}_\lambda \, (\mathbf{1}-\rho_\lambda)\mathbf{d}\lambda}{\int_{\lambda_1}^{\lambda_2} \mathbf{S}_\lambda \, \mathbf{d}\lambda} \quad . \qquad (1)$$

where

$\alpha_s(\lambda_1,\lambda_2)$ = Solar absorptance calculated from λ_1 to λ_2 (250–2500 nm)

S_λ = Solar air mass zero spectral irradiance curve (ASTM E490)

ρ_λ = Measured wavelength-dependent hemispherical reflectance of sample

Inspection of the solar air mass zero spectral irradiance curve in ASTM E490 reveals that 3.9% of the sun's energy falls outside the wavelength region measured by the Lambda-9 spectrometer (250–2500 nm). Depending on the absorptive properties of the samples outside of the measurement range, an error of up to 0.039 (absolute) can be incurred in these calculations. To estimate this error, the calculations using Eq. (1) were also performed assuming total sample absorption outside the 250–2500 measurement range. This worst-case calculation is important for these paints, since the silicate and silicone binders in them absorb strongly in the IR region beyond 2500 nm. Similarly, these paints, like most materials, are also highly absorptive below 250 nm.

Selected measurements on one sample of each material were also made at a 240 nm/min scan rate, with no masking of the samples employed. The results of these measurements were very slightly different from the 480 nm/min masked runs. Only one sample of each material was measured, since it was assumed that the sample was representative of the particular paint batch.

Both sets of data are presented in Table 5, along with the worst-case comparison calculation for both sets of measurements. Calculations and measurements were made to three decimal places; however, the data have been rounded to two decimal places for this work.

5.2.2 Hemispherical Emittance

The Aerospace Corporation had total hemispherical emittance measurements performed on one sample of each of the four paint types. The emittance measurements were performed at McDonnell Douglas Astronautics Corporation, Huntington Beach, California. The measurements were made using a Surface Optics Corporation SOC 100 HDR IR hemispherical reflectometer coupled to a Nicolet Magna IR 550 Fourier transform IR spectrometer. This instrument illuminates the sample hemispherically inside a gold hemisphere using a blackbody source. The sample's IR reflectance is then measured from 2 to 40 µm at various angles by use of a pick-off mirror. The sample is thus illuminated hemispherically and viewed directionally. Measurements are made with parallel polarization, perpendicular polarization, and averaged polarization. Measurements made at 20° approximate the total normal emittance. The emittance at each angle is calculated from the reflectance data at whatever temperature is desired. The total hemispherical emittance is calculated from a weighted average of the scans at the various angles. The emittance data are shown in Tables 6–9. The appendix to this report contains the IR reflectance curves for these samples.

Table 5. Aerospace Solar Absorptance of Disks

Coating	Sample I. D.	Solar Absorptance α_S[1]	Max. Solar Absorptance α_S[2]	Solar Absorptance α_S[3]	Max. Solar Absorptance α_S[2]
YB-71	SN001	0.12	0.15	0.11	0.14
	SN002	0.12	0.15		
	SN003	0.12	0.15		
	SN004	0.13	0.16		
Z-93P	SN005	0.13	0.16	0.13	0.16
	SN006	0.13	0.16		
	SN007	0.14	0.17		
	SN008	0.13	0.16		
S13GP/LO-1	SN009	0.16	0.19	0.17	0.20
	SN010	0.17	0.20		
	SN011	0.18	0.21		
	SN012	0.17	0.19		
MH21S/LO	SN013	0.96	0.96	0.98	0.98
	SN014	0.96	0.96		
	SN015	0.94	0.94		
	SN016	0.95	0.95		

[1]Solar absorptance was measured using a Teflon mask between the sample surface and the integrating sphere. A scan rate of 480 nm/min was used. Correction of the spectrum with a standard NIST 2019d white tile was made with the mask in place during the standard run.

[2]Solar absorptance was calculated assuming 100% sample absorption outside the wavelength region from 250 to 2500 nm.

[3]No masking of the sample was used in these measurements. The scan rate was 240 nm/min. Correction was made with a standard 2019d NIST white tile spectrum.

Table 6. Emittance Measurements on YB-71, SN001

Zenith angle, °	Wave-length, m	Temperature, K				
		200	250	300	350	400
20	2.0-40	0.888	0.908	0.919	0.924	0.924
30	2.0-40	0.881	0.903	0.915	0.920	0.920
40	2.0-40	0.867	0.890	0.904	0.910	0.910
50	2.0-40	0.847	0.872	0.887	0.894	0.895
60	2.0-40	0.795	0.823	0.843	0.853	0.857
68	2.0-40	0.724	0.758	0.783	0.798	0.806
75	2.0-40	0.622	0.656	0.684	0.703	0.715
80	2.0-40	0.415	0.460	0.496	0.522	0.540
Hemi-spherical	2.0-40	0.802	0.828	0.845	0.853	0.856

Table 7. Emittance Measurements on Z-93P, SN005

Zenith angle, °	Wave-length, m	Temperature, K				
		200	250	300	350	400
20	2.0-40	0.943	0.952	0.957	0.959	0.957
30	2.0-40	0.941	0.951	0.956	0.957	0.955
40	2.0-40	0.932	0.944	0.950	0.952	0.950
50	2.0-40	0.916	0.930	0.938	0.941	0.939
60	2.0-40	0.878	0.897	0.909	0.915	0.916
68	2.0-40	0.818	0.845	0.863	0.874	0.878
75	2.0-40	0.713	0.750	0.778	0.796	0.806
80	2.0-40	0.521	0.570	0.607	0.633	0.649
Hemi-spherical	2.0-40	0.873	0.890	0.900	0.905	0.906

Table 8. Emittance Measurements on S13GP/LO-1, SN009

Zenith angle, °	Wave-length, m	Temperature, K				
		200	250	300	350	400
20	2.0-40	0.910	0.923	0.931	0.934	0.935
30	2.0-40	0.909	0.922	0.930	0.933	0.934
40	2.0-40	0.899	0.913	0.922	0.926	0.926
50	2.0-40	0.882	0.897	0.906	0.911	0.912
60	2.0-40	0.845	0.860	0.871	0.876	0.878
68	2.0-40	0.780	0.797	0.810	0.817	0.820
75	2.0-40	0.683	0.702	0.716	0.726	0.731
80	2.0-40	0.488	0.511	0.530	0.545	0.555
Hemi-spherical	2.0-40	0.840	0.855	0.865	0.870	0.872

Table 9. Emittance Measurements on MH21S/LO, SN013

Zenith angle, °	Wave-length, m	Temperature, K				
		200	250	300	350	400
20	2.0-40	0.936	0.940	0.942	0.944	0.947
30	2.0-40	0.934	0.937	0.940	0.942	0.945
40	2.0-40	0.925	0.929	0.933	0.936	0.939
50	2.0-40	0.911	0.916	0.920	0.924	0.929
60	2.0-40	0.880	0.886	0.891	0.897	0.903
68	2.0-40	0.839	0.849	0.858	0.867	0.876
75	2.0-40	0.763	0.779	0.794	0.808	0.822
80	2.0-40	0.545	0.579	0.608	0.635	0.660
Hemi-spherical	2.0-40	0.875	0.881	0.887	0.893	0.898

A comparison of the absorptance and emittance measurements for the four samples is presented in Tables 10 and 11. These values are calculated for the wavelength range 250–2500 nm.

Table 10. Comparison of Solar Absorptance Data

Paint Sample	IITRI Solar Absorptance[1]	Aerospace Solar Absorptance[2]	Aerospace Solar Absorptance[3]
YB-71, SN001	0.11	0.12	0.11
Z-93P, SN005	0.12	0.13	0.13
S13GP/LO-1, SN009	0.16	0.16	0.17
MH21S/LO, SN013	0.97	0.96	0.98

[1]Solar absorptance was measured using a Perkin-Elmer Lambda-19 spectrometer and a integrating sphere detector. A scan rate of 480 nm/min was used. The spectra are corrected to a standard NIST 2019d white tile.

[2]Solar absorptance was measured on a Perkin-Elmer Lambda-9 spectrometer using a Teflon mask between the sample surface and the integrating sphere detector. A scan rate of 480 nm/min was used. Correction of the spectrum with a standard NIST 2019d white tile was made with the mask in place during the standard measurement.

[3]No masking of the sample was used in these measurements. The scan rate was 240 nm/min. Correction was made with a standard 2019d NIST white tile spectrum.

Table 11. Comparison of Emittance Data

Paint Sample	Normal Emittance[1]	Calculated Emittance[2]	20° Emittance[3] (300°K)	Hemispherical Emittance[4] (300 K)
YB-71, SN001	0.89	0.84	0.92	0.85
Z-93P, SN005	0.92	0.86	0.96	0.90
S13GP/LO-1, SN009	0.90	0.85	0.93	0.87
MH21S/LO, SN013	0.90	0.85	0.94	0.89

[1]Total normal emittance was measured using a Gier-Dunkle DB-100 IR reflectometer.

[2]Calculated hemispherical emittance from normal emittance was measured using relationship in *Heat Transfer* (see footnote 4, page 15).

[3]Calculated emittance from IR reflectance was measured at 20° off normal.

[4]Calculated hemispherical emittance from IR reflectance was measured at several angles.

6. Discussion

The average values for the physical and optical properties of each of the four thermal control coatings are presented in Table 12. From the data summarized in Table 10, it can be seen that the various solar absorptance measurements agree very well for the one sample of each coating that was measured. The data in Table 11 indicate that there is some variability in the emittance values. The value used for the average in Table 12 is the average of the calculated emittance from the Gier-Dunkle measurement and the total hemispherical measurement.

Table 12. Average Values for Coating Properties

Coating	Mass Grams	Thickness Mils	Density g/cm^3	Solar Absorptance	Max. Solar Absorptance	Hemispherical Emittance
YB-71	0.2672	8.4	2.68	0.12	0.15	0.85
Z-93P	0.0841	4.8	1.49	0.13	0.16	0.88
S13GP/LO-1	0.2738	9.4	2.49	0.17	0.20	0.86
MH21S/LO	0.0585	3.3	1.53	0.96	0.97	0.87

All specimens were delivered to the SAMMES contractor, RSI, Inc., for integration onto the SAMMES calorimeter module. The samples of S13GP/LO-1 prepared on disks 009–012 and cups 109–112 were returned to Aerospace for rework. The disks and cups had overspray of paint around the edge in excess of the 0.001 in. specification and would not meet the assembly tolerances for the calorimeters. The disk and cup samples were carefully shaved on the affected edges using a new, clean x-acto knife. During examination at Aerospace, it was noticed that some of the disk specimens had become contaminated, and appeared to have fingerprints or black smudges. These marks were removed by cleaning with isopropyl alcohol and a cotton swab. After successful cleaning and drying, the samples were remeasured on the Lambda-9 spectrometer to determine if the cleaning had altered their solar absorptance from the prior rework value. The results of this rework are shown in Table 13.

Table 13. Solar Absorptance of Rework and Cleaned S13GP/LO-1 Samples

Sample #	Solar Absorptance	Max. Solar Absorptance
SN009	0.17	0.20
SN010	0.17	0.20
SN011	0.16	0.20
SN012	0.17	0.20
Average	0.17	0.20

It is concluded from these measurements that the cleaning restored or improved the reflectance of the samples and that contamination was successfully removed.

Appendix

Figures A-1–A-5 show UV-VIS-NIR reflectance curves for YB-71, Z-93P, S13GP/LO-1, and MH21S/LO.

Figures A-6–A-9 show IR reflectance curves for YB-71, Z-93P, S13GP/LO-1, and MH21S/LO.

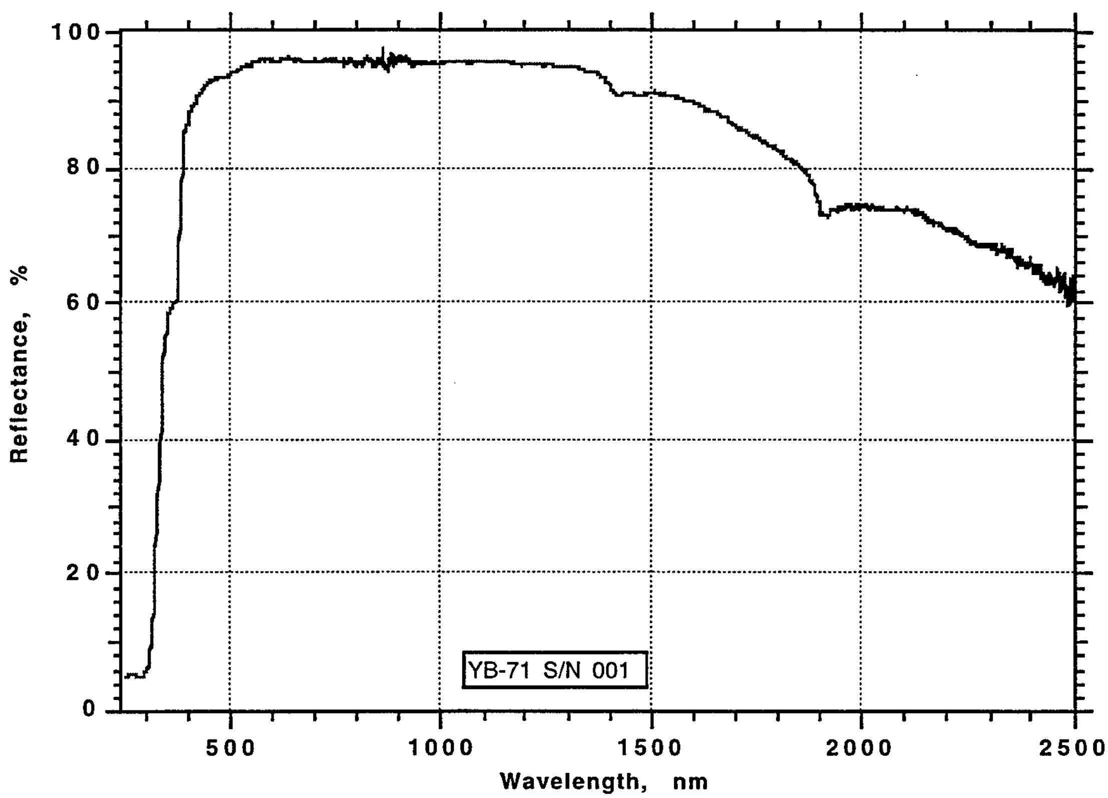

Figure A-1. UV-IVS-NIR reflectance curve for YB-71, S/N 001.

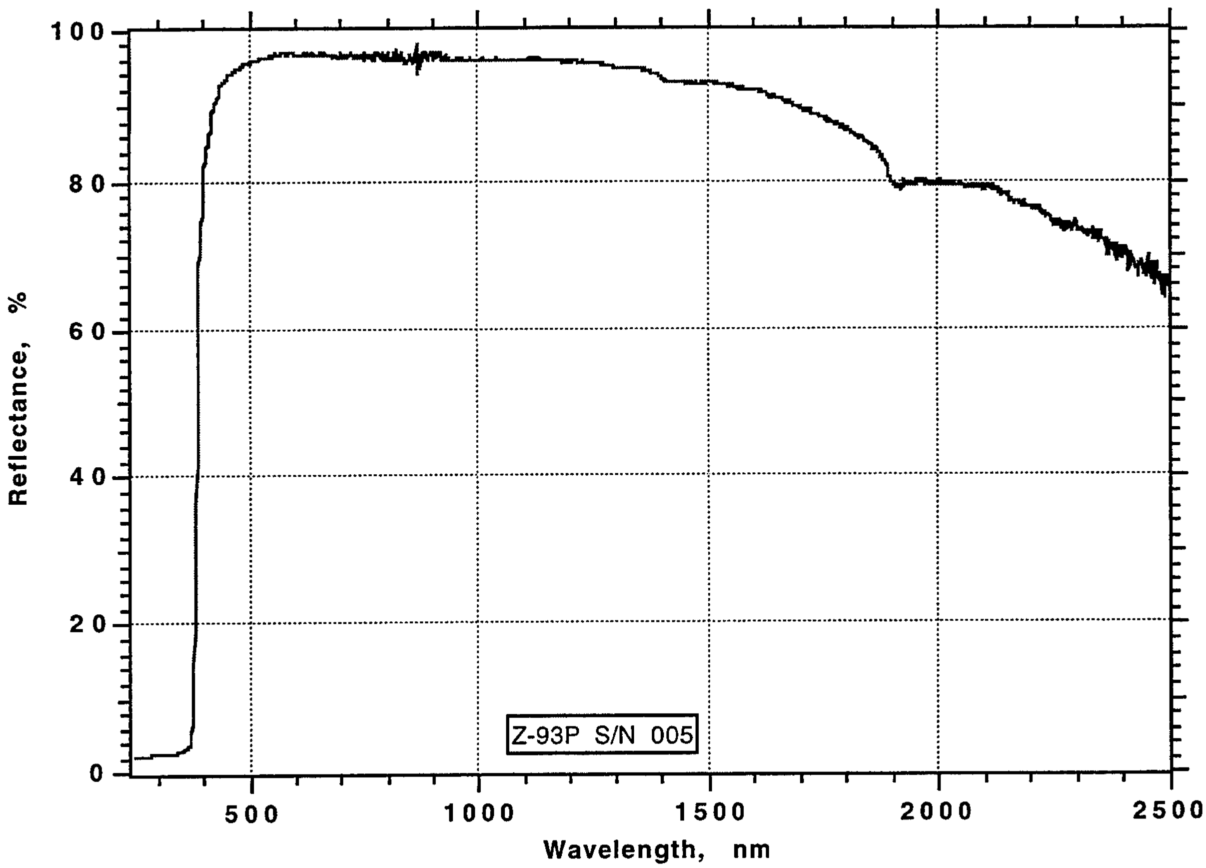

Figure A-2. UV-IVS-NIR reflectance curve for Z-93P, S/N 005.

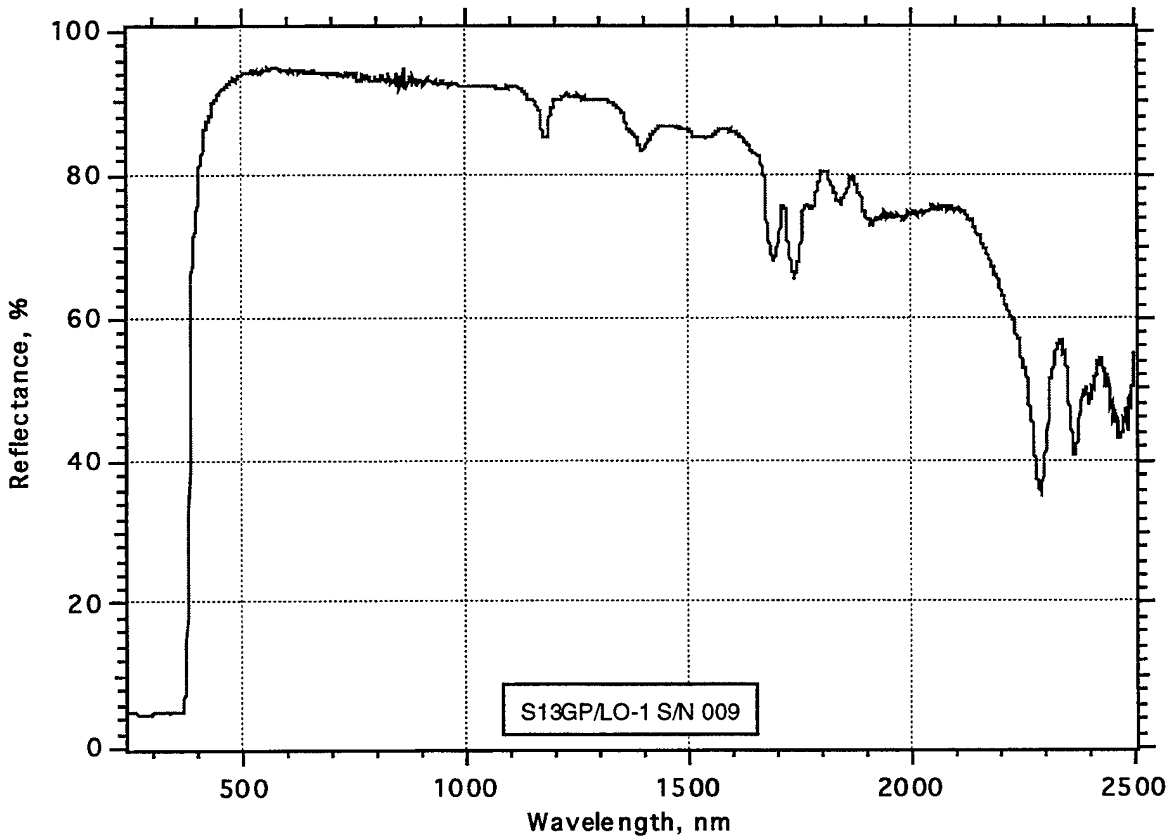

Figure A-3. UV-IVS-NIR reflectance curve for S13GP/LO-1, S/N 009.

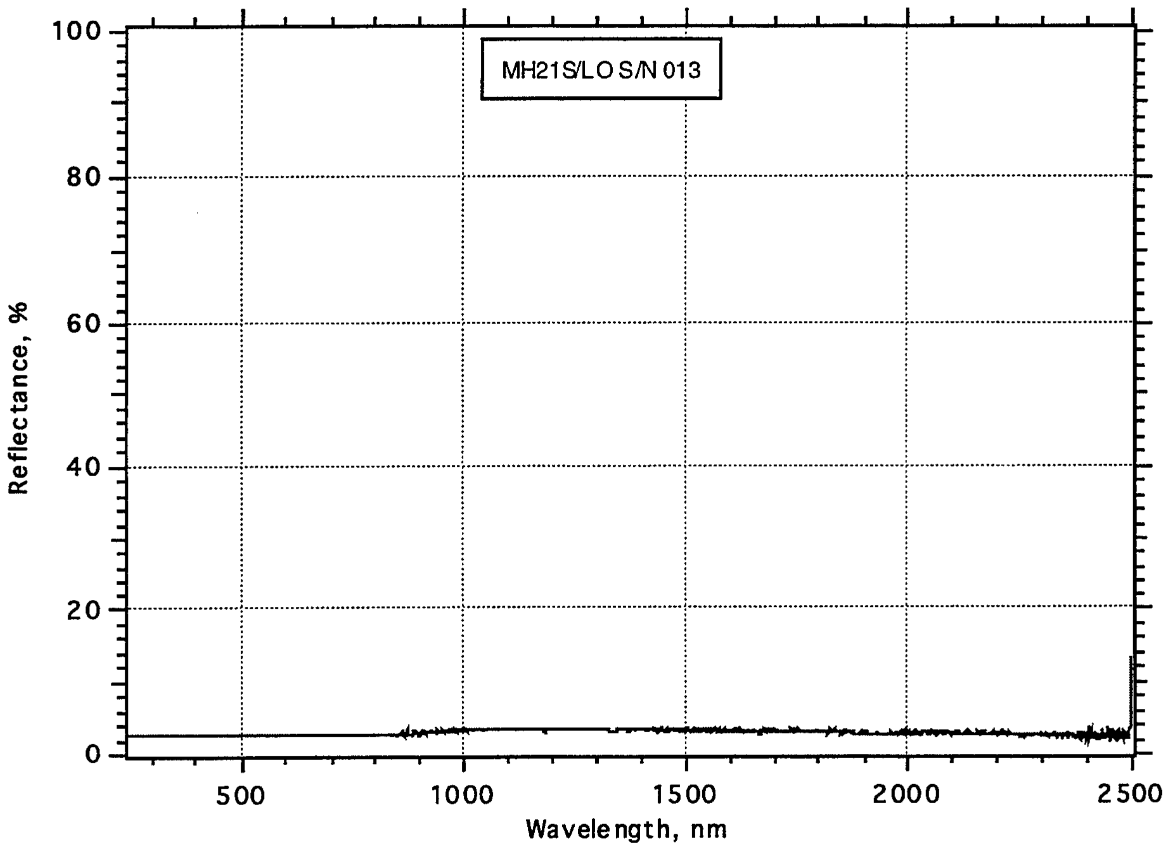

Figure A-4. UV-IVS-NIR reflectance curve for MH21S/LO, S/N 013.

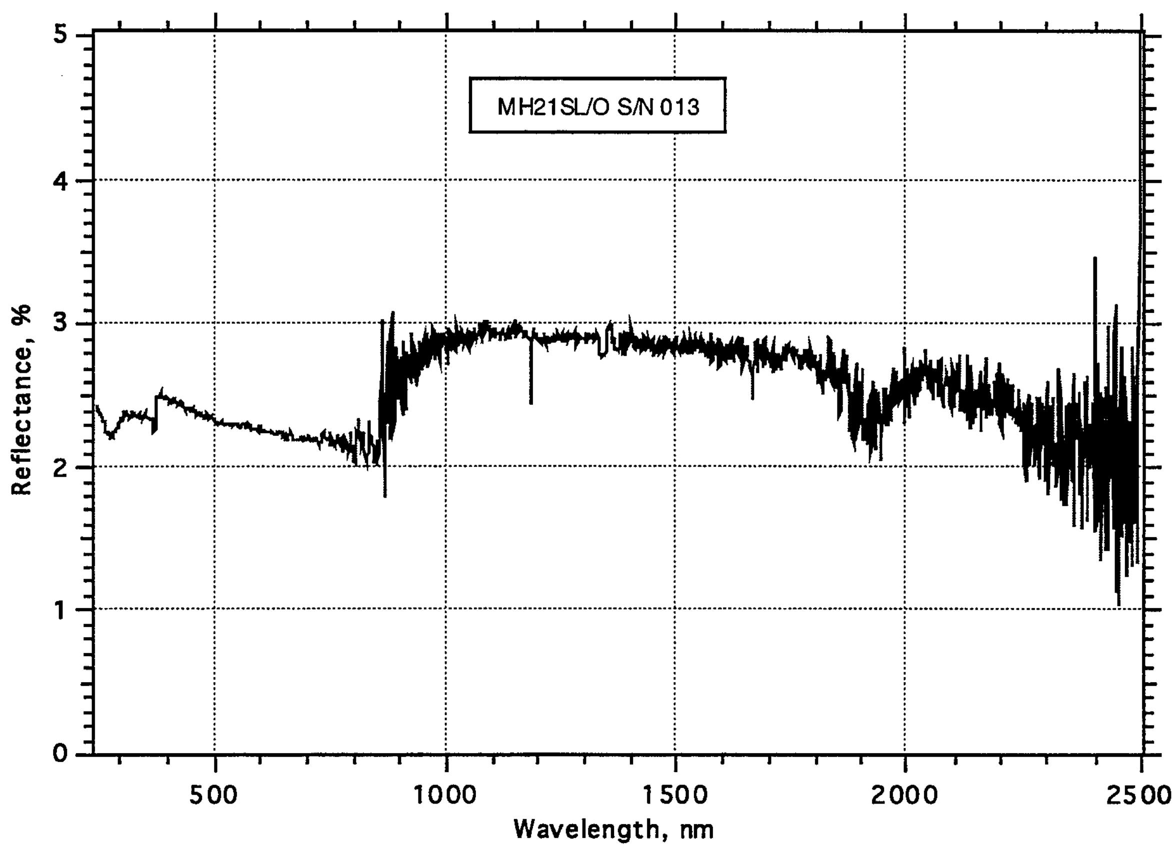

Figure A-5. Expanded UV-IVS-NIR reflectance curve for MH21S/LO S/N 013.

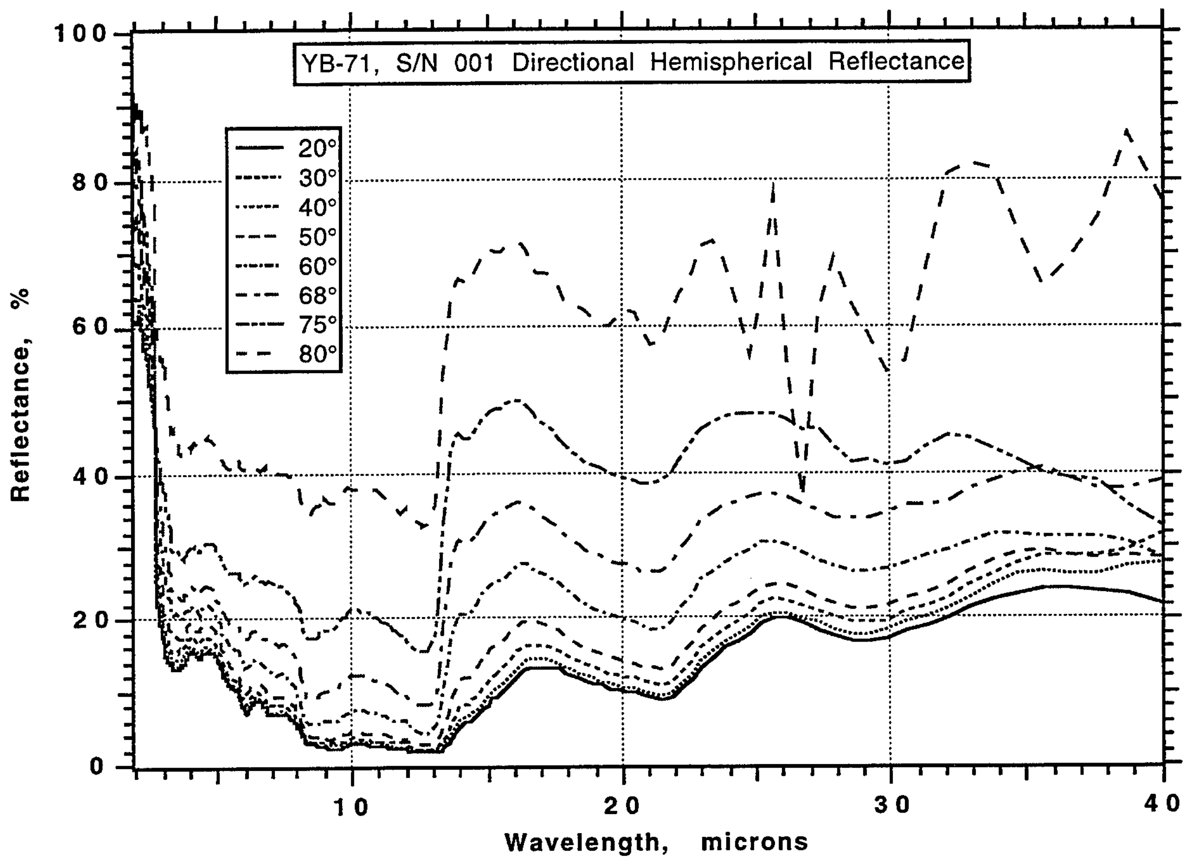

Figure A-6. IR reflectance curve for YB-71, S/N 001.

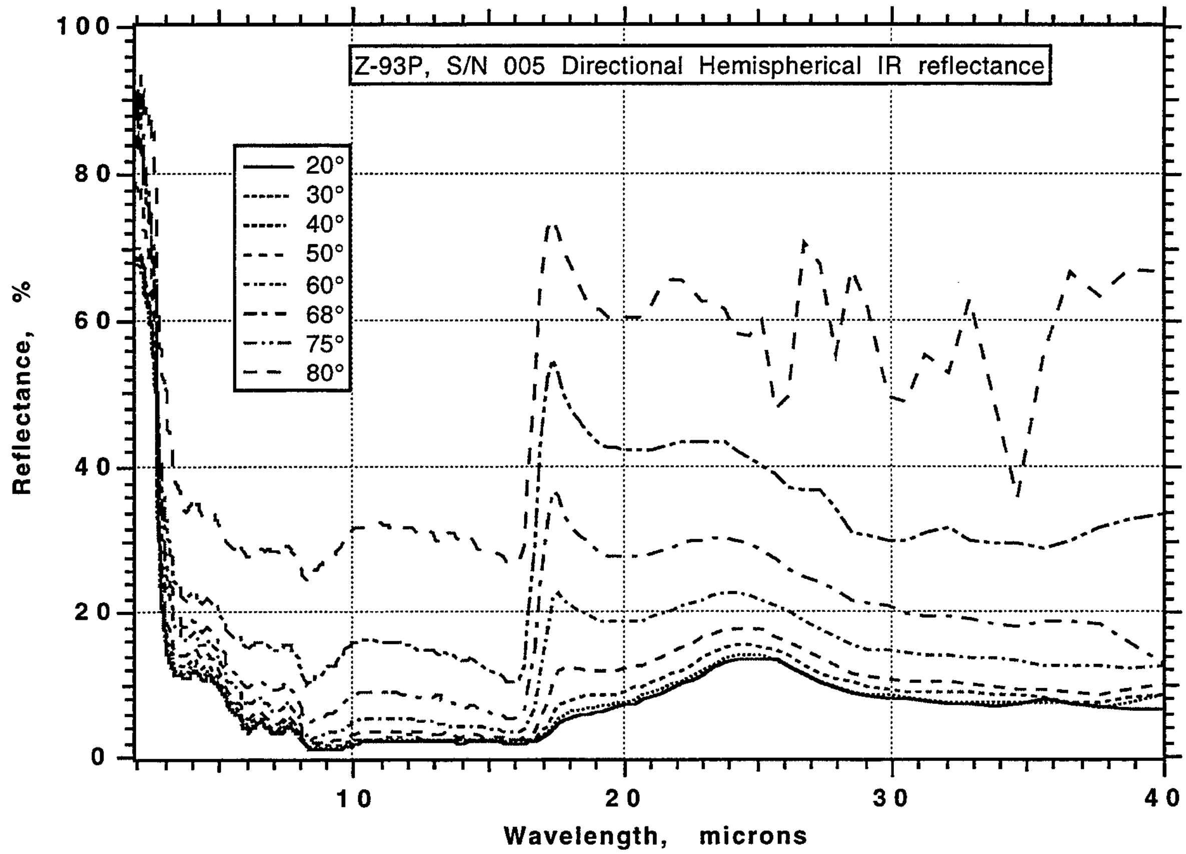

Figure A-7. IR reflectance curve for Z-93P, S/N 005.

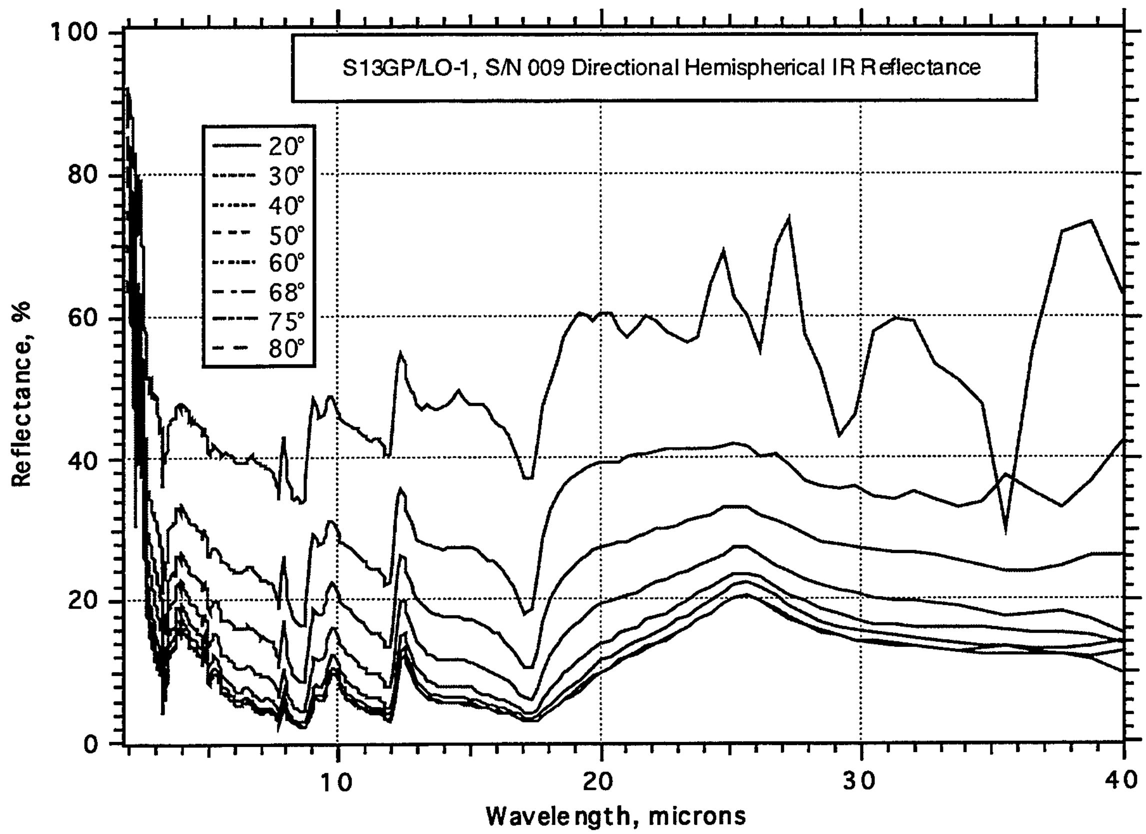

Figure A-8. IR reflectance curve for S13GP/LO-1, S/N 009.

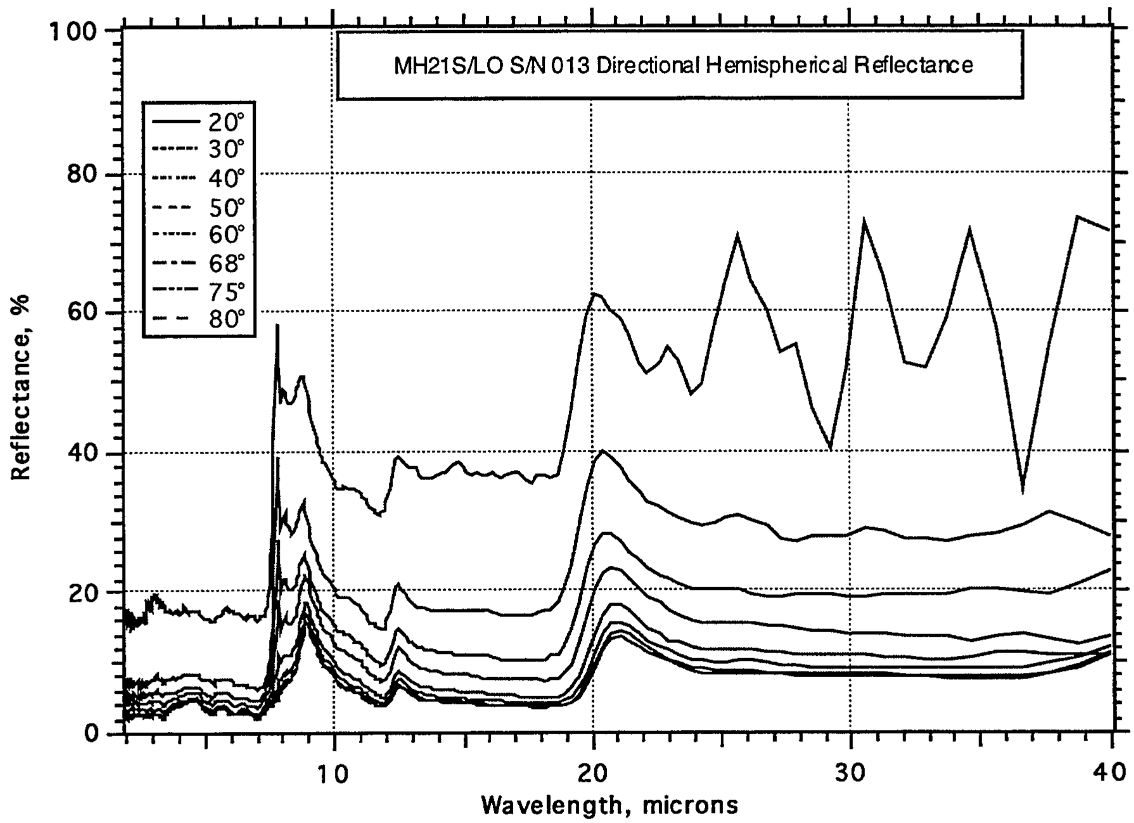

Figure A-9. IR reflectance curve for MH21S/LO, S/N 013.

TECHNOLOGY OPERATIONS

The Aerospace Corporation functions as an "architect-engineer" for national security programs, specializing in advanced military space systems. The Corporation's Technology Operations supports the effective and timely development and operation of national security systems through scientific research and the application of advanced technology. Vital to the success of the Corporation is the technical staff's wide-ranging expertise and its ability to stay abreast of new technological developments and program support issues associated with rapidly evolving space systems. Contributing capabilities are provided by these individual Technology Centers:

Electronics Technology Center: Microelectronics, VLSI reliability, failure analysis, solid-state device physics, compound semiconductors, radiation effects, infrared and CCD detector devices, Micro-Electro-Mechanical Systems (MEMS), and data storage and display technologies; lasers and electro-optics, solid state laser design, micro-optics, optical communications, and fiber optic sensors; atomic frequency standards, applied laser spectroscopy, laser chemistry, atmospheric propagation and beam control, LIDAR/LADAR remote sensing; solar cell and array testing and evaluation, battery electrochemistry, battery testing and evaluation.

Mechanics and Materials Technology Center: Evaluation and characterization of new materials: metals, alloys, ceramics, polymers and composites; development and analysis of advanced materials processing and deposition techniques; nondestructive evaluation, component failure analysis and reliability; fracture mechanics and stress corrosion; analysis and evaluation of materials at cryogenic and elevated temperatures; launch vehicle fluid mechanics, heat transfer and flight dynamics; aerothermodynamics; chemical and electric propulsion; environmental chemistry; combustion processes; spacecraft structural mechanics, space environment effects on materials, hardening and vulnerability assessment; contamination, thermal and structural control; lubrication and surface phenomena; microengineering technology and microinstrument development.

Space and Environment Technology Center: Magnetospheric, auroral and cosmic ray physics, wave-particle interactions, magnetospheric plasma waves; atmospheric and ionospheric physics, density and composition of the upper atmosphere, remote sensing using atmospheric radiation; solar physics, infrared astronomy, infrared signature analysis; effects of solar activity, magnetic storms and nuclear explosions on the earth's atmosphere, ionosphere and magnetosphere; effects of electromagnetic and particulate radiations on space systems; space instrumentation; propellant chemistry, chemical dynamics, environmental chemistry, trace detection; atmospheric chemical reactions, atmospheric optics, light scattering, state-specific chemical reactions and radiative signatures of missile plumes, and sensor out-of-field-of-view rejection.