RE-ORDER NO. 65-1039

STUDY OF THE EFFECT OF JPL STERILIZATION TECHNIQUES ON THERMAL CONTROL SURFACES

JPL Purchase Order No. BF5-326058

P65-173

Paul M. Blair Jr.

December 15, 1965

E. F. Smith

Approved E. F. Smith
Manager Materials Technology Department

Components and Materials Laboratory

Hughes Aircraft Company · Culver City, California

This work was performed for the Jet Propulsion Laboratory, California Institute of Technology, sponsored by the National Aeronautics and Space Administration under Contract NAS7-100.

1 of 24

CONTENTS

		Page
I.	INTRODUCTION	1
II.	SUMMARY	2
III.	TECHNIQUES AND EQUIPMENT	3
IV.	SAMPLE STERILIZATION	7
V.	RESULTS	8
VI.	APPENDIX	17

I. INTRODUCTION

Sterilization of spacecraft may become an accepted practice in the future. Sterilization will be conducted following complete assembly of the spacecraft. The effects, other than biological, on surfaces of materials are of extreme importance to thermal control design engineers. Are there changes in the thermophysical properties of the surface? Are there changes in the behavior of these surfaces when exposed to the space environment? These are questions that this study explored.

It must be pointed out, in the introduction of this report, that this was a very limited study. The limiting factor was the total number of samples studied for each specific condition (i.e., type of surface and type of sterilization). However, this was understood at program inception and the program was conducted to define problem areas and reinforce intuitive feelings about the behavior of certain surfaces to sterilization.

The surfaces studied in this program were chosen by JPL. All the samples were submitted to Hughes by JPL after preparation and sterilization. The surfaces studied were the following:

1. S-13 white paint
2. ARF-2 white paint
3. PV-100 white paint
4. Cat-a-lac flat black paint
5. Buffed aluminum
6. Vacuum deposited aluminum over buffed aluminum
7. Gold plate over buffed aluminum

II. SUMMARY

18443

The effect of several types of sterilization procedures on thermal control surfaces was investigated. Sterilization by ethylene oxide, heat and a combination of the two types were performed on several paint and metallic surfaces. The effects on the solar absorptance and emittance by sterilization on several surfaces can be summarized as follows:

- Metallic surfaces are unaffected by sterilization
- Black coatings are unaffected by sterilization
- Care should be exercised in selecting a sterilizing procedure for white coatings

The results of these tests were based, in the main, on single sample observations. For this reason the results obtained should be used to indicate general trends. In particular, the data generated should not be used for engineering design.

Author

4

III. TECHNIQUES AND EQUIPMENT

A. THERMOPHYSICAL PROPERTIES MEASUREMENT

The Gier-Dunkle integrating sphere and heated Hohlraum (Figure 1) were used to measure sample reflectance (at room temperature) over the range of 0.3 to 25 μ. From the reflectance data the solar absorptance (α_s) and the normal emittance (ϵ) were determined.

The measurement of the reflectance spectrum is made at a set number of wavelengths. The wavelengths are chosen such that each wavelength represents an equal energy band of the solar spectrum or the black body curve ($80^{\circ}F$). To determine the reflectance spectrum of a material, 2 percent energy increments are chosen. The error in making a reflectance measurement is about ± 1.5 percent.[1] This leads to a total error in a calculated solar absorptance of ± 7.5 percent when the α_s = 0.20 (± 5 percent for $\alpha_s = 0.30$).

The instrument yields readings that are highly repeatable. Tests conducted (unknown to operators) on the same sample for as many as 10 separate measurements yielded a spread of ± 0.015 on the calculated α_s.

If the reflectance spectrum of a surface is known it is normally not important to repeat readings at 2 percent energy bands. It is more convenient to choose 10 percent energy bands where only 10 wavelengths (10λ curve) are measured. The values of α_s and ϵ can be calculated from these measurements. The error associated with this shorter measurement is somewhat higher by virtue of fewer measurements, but using the full spectral data as a guide, it is not difficult to spot improper data points.

As an example of the use or possible misuse of the 10λ curve consider the ARF-2 control sample (see Table II). The 50λ curve when integrated yields a solar absorptance of 0.15. From this same curve and using the 10λ data, a solar absorptance of 0.17 is calculated. The very sharp absorption edge of the ZnO leads the 10λ curve to the conclusion that the average reflectance of the first 10 percent band is 1.5 percent while in reality the average reflectance (using the 50 data) is 18 percent.

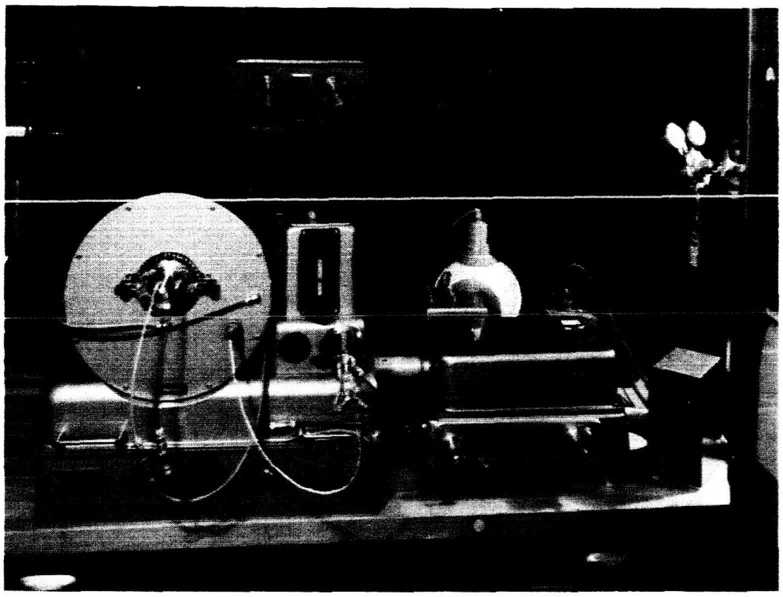

Figure 1. Gier-Dunkle integrating sphere and heated Hohlraum.

B. ULTRAVIOLET EXPOSURE

The exposure of the samples to UV was done in vacuum. The pressure during the exposure was typically between 1×10^{-6} torr and 1×10^{-7} torr. This pressure is somewhat higher than normal since accelerated testing was used. The higher rate of UV photons leads to a higher gas desorption rate and consequently, a higher pressure.

The vacuum chambers used in this program have been described previously.[2] Basically, they are all metal (Figure 2) except the Suprasil quartz window. Each vacuum seal is a metal gasket and the primary pumping is by ion pumps. The ion pumps are started by reducing the pressure with sorption pumps; therefore, no possibility exists for contamination by organic molecules.

The samples are mounted on a pedestal, by clamping, and the temperature is controlled by circulating water through the pedestal. A thermocouple, percussive arc welded to the metal substrate of the sample monitors temperature during irradiation.

The UV source is a BH6 arc lamp operated in a vertical configuration (Figure 3). Each vacuum chamber, containing two samples, is

RE-ORDER NO. 65-1039

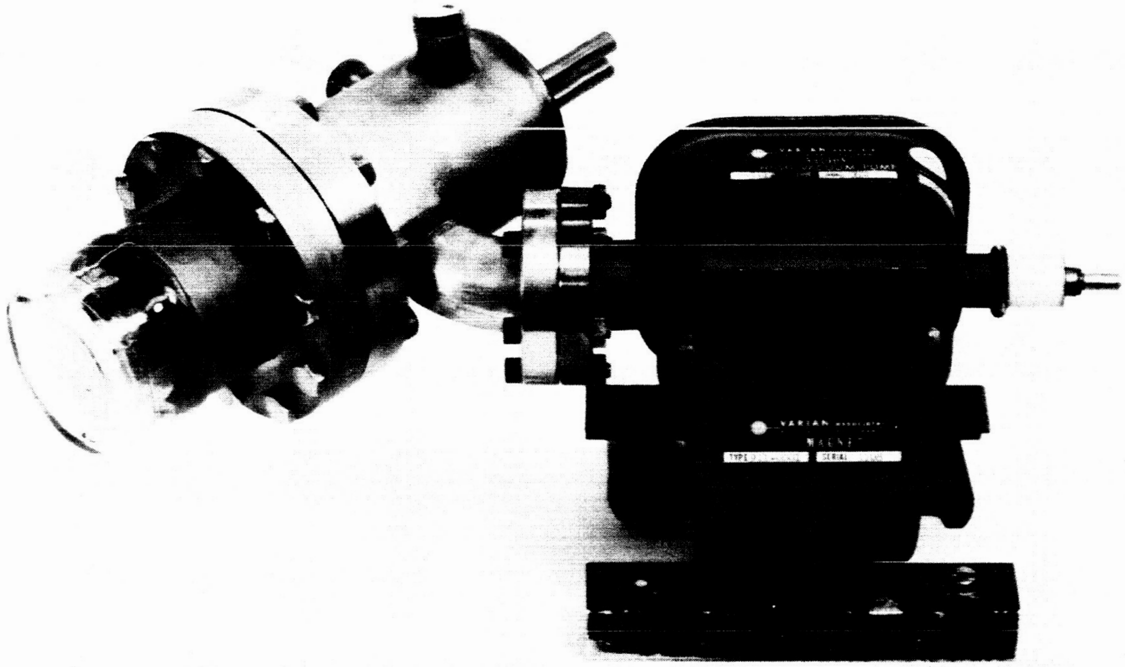

Figure 2. Controlled temperature ultraviolet irradiation chamber.

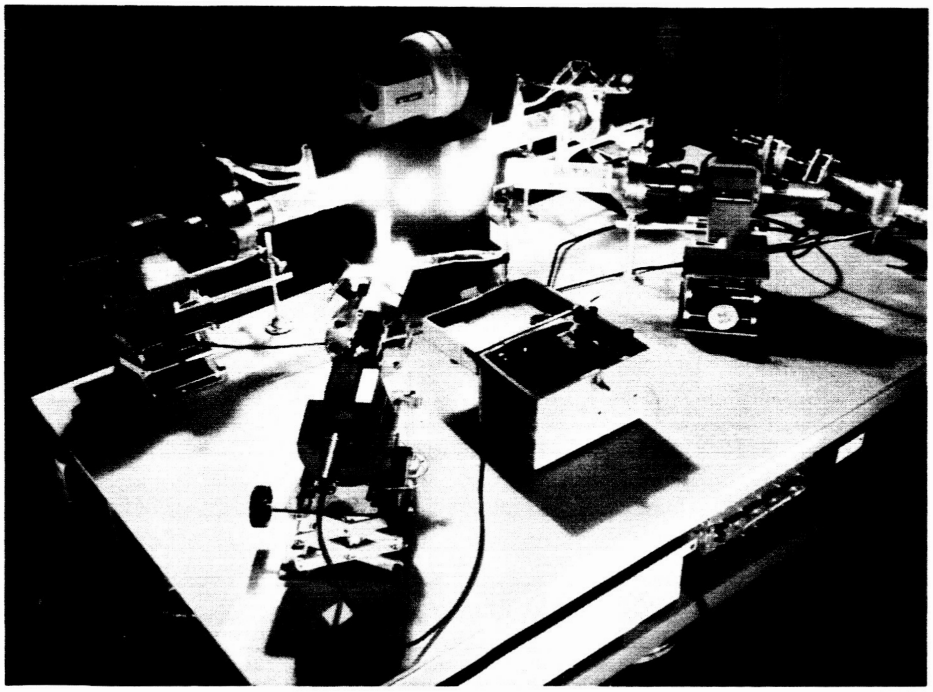

Figure 3. Ultraviolet irradiation facility.

located at the appropriate radial distance from the lamp to obtain the desired intensity of UV.

The UV intensity level is determined by reference to the solar spectrum[3] and considering only that energy contained in the band, 0.2 to 0.4μ. The sample to lamp distance is adjusted so that the energy falling on the sample is equal to the solar energy in this band or some multiple. In tests conducted during this program, intensity level was 5X solar UV, a distance of 7 inches from the source. Since the sample to lamp distance is fixed it is necessary to adjust the UV intensity output. Monitoring of the UV source is accomplished by using filters and a thermopile. The filters isolate, by difference readings, the energy less than 0.3μ being given off by the lamp. By adjusting input power this UV output is held constant (±10 percent). When output falls below -10 percent and cannot be brought back into the range, the lamp is changed.

Wavelengths less than 0.3μ are monitored during tests rather than the complete UV band, 0.2 to 0.4μ. The reason for this is twofold: The BH6 lamp changes spectrally much more drastically with life below 0.3μ, and UV damage to inorganic coatings occurs only from wavelengths less than 0.3μ.

IV. SAMPLE STERILIZATION

Three methods of sterilization were employed by JPL to sterilize the samples tested in this program: ethylene oxide (ETO), heat, and heat plus ethylene oxide.[4]

A. ETO

ETO sterilization was conducted according to JPL Specification GMO-50198-ETS-A. The samples were placed in an atmosphere of 12 percent ETO -88 percent Freon 12, by weight, at 35 percent water vapor humidity. The samples were held at 24°C, in this mixture, for 24 hours, removed and placed in a vacuum chamber for degassing. After degassing, the samples were returned to the ETO-Freon atmosphere and held at 70°C for 24 hours. They were removed and again degassed in a vacuum chamber.

B. HEAT

Heat sterilization was conducted according to JPL Specification XSO-30275-TST-A. The samples were placed in a dry nitrogen atmosphere and heated to 145°C and held at this temperature for 36 hours. The samples were removed, allowed to cool to room temperature and then this cycle was repeated two more times.

C. HEAT + ETO

The samples were first subjected to the ETO sterilization procedure followed by sterilization by heat as described above.

V. RESULTS

Each type of surface was tested independently from other types. The solar absorptance and infrared emittance (normal) of each sample covering all the sterilization techniques for one type of surface were measured. If required, the appropriate UV exposure was given to these samples and the change in solar absorptance was determined. The UV exposure for all samples of a given type was conducted at the same time using the same UV source. This was done so that the parameter of varying UV intensity could be eliminated in the study of several types of sterilization techniques on the same type of surface.

In reviewing the data presented herein, one must keep in mind that in most cases only one sample is tested for each sterilization type. Drawing conclusions other than broad trends should be avoided. In particular, the data should not be used for engineering purposes.

The data can be summarized with three broad statements covering the sterilization techniques studied in this program.

- Metallic surfaces are unaffected by sterilization
- Black coatings are unaffected by sterilization
- Care should be exercised in selecting a sterilizing procedure for white coatings

TEST #1 S-13 WHITE PAINT (TABLE I)

S-13 samples exposed to UV exhibited a very interesting degradation pattern. The solar absorptance of control samples of S-13 increased sharply. This degradation was quite surprising. Samples of S-13 exposed to heat sterilization, in contrast to the control samples, showed excellent stability to UV exposure. It is obvious that the heat (145°C) cured the coating (or removed the degradable products) much more efficiently than the cure given the control samples.

Ethylene oxide (ETO) affects the stability of the S-13 coating. On the samples sterilized by ETO only, the effect is masked by the high degradation due to incomplete curing. Those samples sterilized by ETO and heat, however, show the effect quite clearly.

Sample Number	Solar Absorptance (α_s)				Change in Solar Absorptance $\Delta\alpha_s$	Normal Emittance		Sterilization	Average Temperature During Irradiation (°F)	Coating Thickness (mils)
	Before UV		After UV*							
	α_{50}	α_{10}	α_{50}	α_{10}		ϵ_{50}	ϵ_{10}			
1	0.24		0.42		0.18			Unsterilized	100	5.0
2	—		—		—	0.89		Unsterilized	--	5.5
3	0.22		0.42		0.20	—		ETO	100	5.9
4	—		—		—		0.88	ETO	--	4.7
5A		0.23		0.25	0.02	—		Heat	95	6.0
5B		0.26		0.27	0.01	—		Heat	95	4.1
6	—		—		—		0.88	Heat	--	5.1
7	0.24		0.29		0.05	—		Heat + ETO	95	5.0
8		0.24		0.30	0.06	—		Heat + ETO	95	5.3
9	—		—		—	0.89		Heat + ETO	--	6.7
10	—		—		—		0.88	Heat + ETO	--	4.5
11		0.24		0.41**	0.17	—		Unsterilized	85	5.2
12		0.24		0.26**	0.02	—		Heat	85	4.9

*UV exposure: 168 hours at 5X.
**UV exposure: 144 hours at 5X.

Table I. The effect of sterilization techniques and ultraviolet irradiation on the thermophysical properties of samples of S-13 white paint.

The various sterilization techniques do not affect the initial values of the solar absorptance or the normal infrared emittance of S-13.

TEST #2 ARF-2 WHITE PAINT (Z-93) (TABLE II)

It is somewhat difficult to ascribe any definite trend to this test. The data generally falls within an expected scatter band both before and after UV exposure. As mentioned earlier the 10λ curve yields an α_s that is high by 0.01 or 0.02 units. The data in the table (under α_{10}) has not been corrected to reflect this. Primarily the results of this test are that there is no major change in the α_s due to sterilization nor is there a major increase in the UV degradation of the sterilized surfaces.

The emittance of this coating is not affected by sterilization.

TEST #3 PV-100 WHITE PAINT (TABLE III)

Temperature has a marked effect on the solar absorptance of PV-100. This effect does not, however, change the UV degradation of PV-100. ETO appears to have no effect on the coating.

Sterilization does not affect the emittance of PV-100 white paint.

TEST #4 CAT-A-LAC FLAT BLACK PAINT (TABLE IV)

Sterilization has no effect on the solar absorptance, change in solar absorptance when exposed to UV, or the emittance of Cat-a-lac Flat Black Paint. Although two samples had a 0.01 decrease in α_s after UV exposure, this can be discounted since it falls within expected data scatter.

TEST #5 BUFFED ALUMINUM (TABLE V)

TEST #6 Vapor Deposited Aluminum Over Buffed Aluminum (Table VI).

TEST #7 Gold Plate Over Buffed Aluminum (Table VII).

Surfaces of samples from Test #5, Test #6 and Test #7 are unaffected by sterilization. The variation in α_s of buffed aluminum is due to variation in buffing, sample to sample.

IV

Sample Number	Solar Absorptance (α_s)				Change in Solar Absorptance $\Delta\alpha_s$	Normal Emittance		Sterilization	Average Temperature During Irradiation (°F)	Coating Thickness (mils)
	Before UV		After UV*							
	α_{50}	α_{10}	α_{50}	α_{10}		ϵ_{50}	ϵ_{10}			
1	0.15		0.18		0.03	—		Unsterilized	95	7.4
2	—		—		—	0.93		Unsterilized	—	7.9
3	0.16		0.20		0.04	—		ETO	Broken thermo-couple**	6.7
4	—		—		—		0.92	ETO	—	6.9
5A		0.18		0.22	0.04	—		Heat	95	6.8
5B		0.19		0.24	0.05	—		Heat	110	6.2
6	—		—		—		0.93	Heat	—	6.9
7	0.17		0.20		0.03	—		Heat + ETO	110	7.1
8		0.19		0.23	0.04	—		Heat + ETO	Broken thermo-couple**	7.6
9	—		—		—	0.93		Heat + ETO	—	7.4
10	—		—		—		0.93	Heat + ETO	—	7.5

*UV exposure: 168 hours at 5X.
**Estimated 100 degrees.

Table II. The effect of sterilization techniques and ultraviolet irradiation on the thermophysical properties of samples of ARF-2 white paint.

Sample Number	Solar Absorptance (α_s)				Change in Solar Absorptance $\Delta\alpha_s$	Normal Emittance		Sterilization	Average Temperature During Irradiation (°F)	Coating Thickness (mils)
	Before UV		After UV*							
	α_{50}	α_{10}	α_{50}	α_{10}		ϵ_{50}	ϵ_{10}			
1	0.25		0.31		0.06		–	Unsterilized	Broken thermo-couple**	1.6
2	–		–		–	0.87		Unsterilized	–	1.6
3		0.25		0.30	0.05		–	ETO	Broken thermo-couple**	1.5
4	–		–		–		0.87	ETO	–	1.7
5		0.29		0.34	0.05		–	Heat	95	2.1
6	–		–		–		0.87	Heat	–	2.0
7	0.28		0.33		0.05		–	Heat + ETO	95	1.8
8		0.28		0.33	0.05		–	Heat + ETO	80	1.8
9	–		–		–	0.87		Heat + ETO	–	1.9
10	–		–		–		0.87	Heat + ETO	–	1.9

*UV exposure: 24 hours at 5X.
**Estimated 90 degrees.

Table III. The effect of sterilization techniques and ultraviolet irradiation on the thermophysical properties of samples of PV-100 white paint.

+

Sample Number	Solar Absorptance (α_s)				Change in Solar Absorptance	Normal Emittance		Sterilization	Average Temperature During Irradiation (^oF)	Coating Thickness (mils)
	Before UV		After UV*							
	α_{50}	α_{10}	α_{50}	α_{10}	$\Delta\alpha_s$	ϵ_{50}	ϵ_{10}			
1	0.96		0.96		0.00		—	Unsterilized	Broken thermo-couple**	2.0
2	—		—		—	0.91		Unsterilized	—	2.1
3		0.95		0.94	-0.01		—	ETO	Broken thermo-couple**	2.1
4	—		—		—		0.91	ETO	—	2.2
5		0.96		0.96	0.00		—	Heat	90	2.9
6	—		—		—		0.91	Heat	—	2.9
7		0.96		0.95	-0.01		—	Heat + ETO	90	2.9
8	—		—		—	0.90		Heat + ETO	—	2.1

*UV exposure: 24 hours at 5X.
**Estimated 90 degrees.

Table IV. The effect of sterilization techniques and ultraviolet irradiation on the thermophysical properties of samples of Cat-a-lac flat black paint.

15

Sample Number	Solar Absorptance (α_s)		Normal Emittance		Sterilization
	α_{50}	α_{10}	ϵ_{50}	ϵ_{10}	
1	0.23		0.04		Unsterilized
2		0.22		0.04	ETO
3		0.23		0.04	Heat
4		0.26	0.04		Heat + ETO

Table V. The effect of sterilization techniques on the thermophysical properties of samples of buffed aluminum.

Sample Number	Solar Absorptance (α_s)		Normal Emittance		Sterilization
	α_{50}	α_{10}	ϵ_{50}	ϵ_{10}	
1	0.11		0.03		Unsterilized
2		0.11		0.03	ETO
3		0.11		0.03	Heat
4		0.12	0.03		Heat + ETO

Table VI. The effect of sterilization techniques on the thermophysical properties of samples of vapor deposited aluminum over buffed aluminum.

16

Sample Number	Solar Absorptance (α_s)		Normal Emittance		Sterilization
	α_{50}	α_{10}	ϵ_{50}	ϵ_{10}	
1	0.25		0.03		Unsterilized
2		0.24		0.03	ETO
3		0.24		0.03	ETO
4		0.23		0.03	Heat
5		0.23		0.03	Heat
6		0.23		0.03	Heat + ETO
7		0.23		0.03	Heat + ETO

Table VII. The effect of sterilization techniques on the thermophysical properties of samples of gold plate over buffed aluminum.

REFERENCES

1. D.K. Edwards, et al., "Basic Studies on the Use and Control of Solar Energy." Report No. 60-93 UCLA August 1960.
2. Blair G.R. and Blair P.M., "An Ultrahigh Vacuum, Controlled Temperature, Ultraviolet Irradiation Chamber." Trans American Vacuum Society, 1963.
3. "Handbook of Geophysics," Macmillan Co. (1961).
4. W.H. Hall, Private Communication.

ACKNOWLEDGMENT

B.J. Kehoe for data reduction.

H.B. Lyman for UV testing.

VI. APPENDIX

Reflectance Data Used for Determination of the Solar Absorptance

Test #1 S-13 White Paint

Percent Reflectance

Wavelength (Micron)	Sample 1		Sample 3		Sample 5A		Sample 5B		Sample 7		Sample 8		Sample 11		Sample 12	
	Before UV	After UV	Before UV	After UV	Before UV	After UV	Before UV	After UV	Before UV	After UV	Before UV	After UV	Before UV	After UV	Before UV	After UV
0.295	0	0	0	0					0	0						
0.330	2.0	0	1.5	0					1.5	0						
0.355	2.5	0	3.0	0	1.0	1.0	1.0	1.0	3.0	0	1.0	1.0	1.0	1.0	1.0	1.0
0.377	21.0	1.5	19.5	2.5					21.0	10.0						
0.400	69.0	14.5	69.0	16.5					69.0	44.0						
0.415	80.0	18.5	79.0	21.5					78.5	53.5						
0.430	85.5	25.5	84.5	27.0					83.0	61.5						
0.445	88.0	29.0	87.0	30.5	83.0	74.0	83.0	75.0	85.5	65.0	83.5	58.0	85.0	30.0	83.5	74.5
0.458	89.0	32.5	88.0	34.0					87.0	69.0						
0.470	89.5	34.5	88.5	36.0					87.0	71.0						
0.484	89.5	37.5	89.5	39.0					87.5	73.5						
0.497	90.0	40.5	90.0	42.0					88.0	76.0						
0.511	90.0	43.0	90.5	44.5	89.5	84.5	88.0	84.0	88.5	77.5	89.0	73.0	90.0	47.0	88.0	84.0
0.526	90.0	46.5	91.0	47.5					89.0	79.0						
0.540	90.0	49.0	91.0	50.5					89.5	80.0						
0.554	90.0	52.0	91.0	53.0					89.5	81.0						
0.569	90.0	54.5	91.0	55.0					89.0	81.5						
0.584	90.0	57.5	91.0	57.5	90.5	88.0	88.0	86.0	89.5	82.5	90.5	81.0	90.0	60.0	89.0	87.5
0.598	90.0	59.0	91.5	59.5					89.5	83.0						
0.614	90.0	61.5	91.0	61.0					89.5	84.0						
0.630	90.0	62.5	90.5	63.0					89.0	84.5						
0.646	89.0	65.0	90.0	63.0					89.0	84.5						
0.664	89.0	66.5	90.5	66.5	90.5	88.5	88.0	86.0	88.5	85.0	89.5	83.0	89.5	68.5	89.5	87.0
0.681	88.0	67.5	90.0	67.5					89.0	86.0						
0.700	88.5	71.5	89.5	70.5					88.5	85.5						
0.718	87.5	72.5	89.5	72.5					88.5	86.0						
0.738	88.0	75.5	89.5	75.0					88.5	86.0						
0.759	88.0	76.5	89.5	76.0	89.5	89.0	87.5	85.0	88.0	86.0	88.5	86.0	88.0	75.0	88.5	88.0
0.781	87.0	77.0	89.0	78.0					87.5	86.0						
0.804	87.0	78.0	88.5	79.5					87.0	86.0						
0.828	86.5	79.5	88.0	80.5					87.0	85.5						
0.853	86.5	80.0	88.0	81.5					86.0	85.5						
0.880	85.5	81.5	87.5	82.0	88.5	87.5	84.0	83.5	86.0	85.0	86.5	85.5	86.5	82.0	86.5	85.0
0.910	85.0	81.5	87.0	82.5					85.0	84.5						
0.940	84.5	81.5	86.5	83.0					85.0	84.0						
0.974	84.0	81.5	86.0	83.0					84.5	83.5						
1.011	83.5	82.0	85.5	83.0					83.5	83.5						
1.052	82.5	81.5	85.0	83.5	86.0	85.5	81.0	81.0	83.0	83.0	84.0	84.0	83.0	82.5	83.5	83.0
1.096	82.0	81.0	84.5	82.5					82.0	82.5						
1.148	80.5	80.0	82.5	81.5					80.5	80.5						
1.200	80.0	79.0	81.0	81.0					79.5	79.0						
1.267	79.5	79.0	81.0	80.5					80.0	79.0						
1.341	77.5	77.5	80.0	79.5	81.0	80.5	76.5	76.5	78.0	78.0	79.0	79.0	78.0	77.5	78.5	79.0
1.428	76.0	75.5	78.0	77.5					76.0	76.0						
1.536	74.5	74.0	76.5	76.5					74.5	74.5						
1.671	67.5	68.5	71.0	71.5					70.5	70.0						
1.854	68.5	67.5	69.5	69.0					69.0	69.5						
2.120	59.5	61.0	62.5	64.5	64.5	63.0	63.0	63.5	63.5	63.5	63.5	63.0	61.5	62.0	63.5	63.5
2.600	47.0	67.0	47.5	46.0					50.5	49.5						
3.900	—	—	—	—					—	—						

Test #2 ARF-2 White Paint

Wavelength (Micron)	Percent Reflectance											
	Sample 1		Sample 3		Sample 5A		Sample 5B		Sample 7		Sample 8	
	Before UV	After UV	Before UV	After UV	Before UV	After UV	Before UV	After UV	Before UV	After UV	Before UV	After UV
0.295	0	0	0	0					0	0		
0.330	0	0	0.5	0					0	0		
0.355	1.5	0	2.0	0	1.0	1.0	1.0	1.0	1.5	0	1.0	1.0
0.377	15.5	10.5	17.0	13.0					14.0	13.5		
0.400	73.5	62.5	74.5	62.0					67.5	58.0		
0.415	86.5	76.0	86.5	72.5					79.5	70.5		
0.430	91.5	82.5	90.5	78.0					85.0	76.0		
0.445	92.5	85.0	92.0	80.5	85.5	70.5	84.5	65.5	87.0	79.0	85.5	70.5
0.458	93.0	87.0	92.5	81.5					88.5	80.5		
0.470	93.5	86.5	93.0	82.0					89.0	82.5		
0.484	93.5	87.0	93.0	83.5					90.0	83.5		
0.497	94.0	88.0	93.0	84.5					90.5	84.5		
0.511	94.0	88.5	93.5	85.5	91.5	81.0	90.5	77.0	91.5	85.5	91.0	81.0
0.526	94.0	89.5	93.5	85.5					91.5	86.5		
0.540	94.5	90.0	94.0	86.5					92.0	87.5		
0.554	94.5	90.5	94.0	87.5					93.0	88.5		
0.569	94.0	90.5	94.0	87.5					93.0	89.0		
0.584	94.5	90.5	94.0	88.0	93.0	86.5	92.5	83.5	93.0	89.5	93.0	86.0
0.598	94.5	91.0	94.0	88.0					93.0	90.0		
0.614	94.5	91.5	94.5	88.5					93.0	90.5		
0.630	94.0	91.5	94.0	89.0					93.0	91.0		
0.646	95.0	92.0	94.0	89.0					93.5	91.0		
0.664	94.5	92.0	94.0	90.0	94.0	89.5	93.5	87.5	93.5	91.5	93.5	88.0
0.681	94.5	92.5	94.0	90.5					94.0	91.0		
0.700	95.0	92.5	94.0	91.0					94.5	92.0		
0.718	95.0	93.0	95.0	91.5					94.5	92.5		
0.738	95.0	93.5	94.5	92.0					94.5	92.5		
0.759	95.5	93.5	94.5	92.0	95.5	92.5	94.0	90.5	94.5	93.5	94.5	91.5
0.781	95.0	94.5	94.5	91.5					94.0	93.5		
0.804	95.0	94.0	94.5	91.5					94.5	93.0		
0.828	95.0	94.0	93.5	91.5					94.0	93.5		
0.853	95.0	94.0	94.5	92.5					94.0	93.5		
0.880	95.0	94.0	94.0	92.5	95.5	94.0	93.5	92.5	94.0	93.5	94.5	92.5
0.910	94.5	94.0	94.0	92.5					94.0	93.5		
0.940	95.0	94.0	94.0	92.5					94.0	93.0		
0.974	94.5	94.0	94.0	93.5					94.0	93.5		
1.011	94.5	94.0	94.5	93.0					94.0	93.0		
1.052	95.0	94.5	94.0	93.0	94.5	94.5	93.5	93.5	94.0	92.5	94.0	93.5
1.096	94.5	94.0	94.0	93.0					94.0	93.5		
1.148	94.5	93.5	94.0	92.5					93.5	93.0		
1.200	94.5	93.5	94.0	92.5					93.5	93.0		
1.267	94.5	93.5	93.5	92.5					93.0	92.5		
1.341	93.5	93.5	93.0	92.5	93.5	93.5	92.5	92.0	92.0	92.5	92.0	93.0
1.428	92.0	92.5	91.5	91.5					91.5	91.0		
1.536	91.5	91.5	90.5	90.5					90.5	90.5		
1.671	89.0	89.0	89.0	88.5					87.5	87.5		
1.854	81.5	83.0	82.5	82.5					82.0	81.5		
2.120	76.5	77.5	77.0	77.5	76.0	76.0	73.5	73.5	75.5	75.5	75.5	75.0
2.600	66.5	67.5	67.0	67.0					65.0	65.0		
3.900	—	—	—	—					—	—		

Test #3 PV-100 White Paint

Wavelength (Micron)	Percent Reflectance									
	Sample 1		Sample 3		Sample 5		Sample 7		Sample 8	
	Before UV	After UV	Before UV	After UV	Before UV	After UV	Before UV	After UV	Before UV	After UV
0.295	0	0					0	0		
0.330	1.5	1.0					1.5	1.5		
0.355	3.0	3.0	3.0	3.0	3.0	3.0	3.5	3.5	3.0	3.0
0.377	9.0	8.0					9.5	8.0		
0.400	36.0	27.0					33.0	26.0		
0.415	60.5	39.0					51.5	38.5		
0.430	78.0	49.5					63.0	48.0		
0.445	81.0	54.5	76.5	56.0	59.5	43.0	65.5	52.0	62.0	45.0
0.458	82.5	58.5					67.0	55.5		
0.470	83.5	61.5					69.0	58.0		
0.484	84.5	64.5					70.5	60.5		
0.497	85.0	68.0					72.5	64.0		
0.511	86.0	70.5	85.5	74.0	71.5	60.5	74.5	66.0	74.0	63.0
0.526	86.5	73.5					75.5	68.0		
0.540	87.0	75.0					77.5	70.5		
0.554	87.0	77.0					78.5	72.5		
0.569	87.5	78.0					79.5	73.5		
0.584	87.5	79.0	86.5	80.0	79.0	71.0	80.5	75.5	80.5	73.5
0.598	87.5	80.0					81.5	76.0		
0.614	87.5	80.0					82.5	77.5		
0.630	87.5	81.0					83.0	78.5		
0.646	87.0	81.0					83.5	79.5		
0.664	87.5	81.0	86.5	82.5	82.0	77.5	83.5	81.0	83.5	78.5
0.681	86.5	82.0					84.0	82.5		
0.700	86.5	83.0					85.0	82.5		
0.718	86.5	84.0					85.5	83.0		
0.738	86.5	84.0					86.5	83.5		
0.759	86.5	84.0	86.5	83.0	85.5	82.0	86.5	83.0	85.5	83.0
0.781	86.5	84.0					86.5	84.5		
0.804	85.5	84.0					86.5	83.0		
0.828	85.0	83.0					86.5	83.0		
0.853	85.5	83.0					86.0	83.0		
0.880	85.5	83.0	85.0	83.0	86.5	84.0	86.0	83.5	86.0	83.5
0.910	85.0	83.0					85.5	84.0		
0.940	84.5	82.0					85.5	83.0		
0.974	85.0	82.0					85.0	82.0		
1.011	85.0	81.5					84.5	80.5		
1.052	83.5	81.5	83.5	81.5	85.0	84.0	84.0	80.5	85.0	83.5
1.096	83.0	81.5					83.5	80.5		
1.148	82.5	80.5					83.0	79.5		
1.200	82.0	80.0					83.0	78.5		
1.267	81.5	80.0					82.0	78.5		
1.341	80.5	79.0	80.0	79.0	82.0	81.0	81.5	77.0	82.5	81.5
1.428	79.0	77.5					80.5	77.0		
1.536	78.5	76.5					80.0	76.5		
1.671	76.0	74.5					77.5	73.0		
1.854	75.0	74.0					76.5	75.0		
2.120	70.5	69.5	70.5	70.5	73.0	72.5	73.0	68.0	74.0	74.0
2.600	61.5	60.0					63.5	62.0		
3.900	–	–					–	–		

Test #4 CAT-A-LAC Flat Black Paint

Wavelength (Micron)	Percent Reflectance							
	Sample 1		Sample 3		Sample 5		Sample 7	
	Before UV	After UV	Before UV	After UV	Before UV	After UV	Before UV	After UV
0.295	0	0						
0.330	0	0						
0.355	0.5	0	1.0	1.0	1.0	1.0	1.0	1.0
0.377	1.5	0						
0.400	2.0	0.5						
0.415	2.0	1.0						
0.430	4.5	5.5						
0.445	4.5	6.0	5.0	6.5	4.5	5.5	4.5	5.5
0.458	4.5	6.0						
0.470	4.5	6.0						
0.484	4.5	5.5						
0.497	5.0	5.5						
0.511	5.0	5.5	5.0	6.5	4.0	5.0	4.0	5.0
0.526	4.5	5.5						
0.540	4.5	5.5						
0.554	4.5	5.5						
0.569	4.5	5.5						
0.584	4.5	4.5	5.0	6.0	4.5	4.5	4.0	5.5
0.598	4.5	5.0						
0.614	5.0	5.5						
0.630	4.5	5.5						
0.646	4.5	5.5						
0.664	4.0	4.0	4.5	5.0	3.5	3.5	3.5	3.5
0.681	3.5	2.0						
0.700	3.5	1.0						
0.718	4.0	2.5						
0.738	3.5	2.0						
0.759	3.5	2.0	3.0	5.0	2.5	3.0	2.5	2.0
0.781	3.5	2.5						
0.804	3.0	2.5						
0.828	3.5	2.5						
0.853	3.5	3.0						
0.880	3.5	3.5	4.0	5.0	4.0	3.0	3.5	4.0
0.910	3.5	4.5						
0.940	4.0	4.5						
0.974	4.5	5.5						
1.011	4.0	4.0						
1.052	4.5	5.0	4.5	5.0	4.0	4.0	4.0	4.5
1.096	4.5	5.0						
1.148	4.5	5.0						
1.200	4.5	5.0						
1.267	4.5	5.0						
1.341	5.0	5.5	5.0	5.5	5.0	4.5	4.5	5.0
1.428	5.0	5.5						
1.536	5.5	5.0						
1.671	5.0	5.5						
1.854	5.0	5.0						
2.120	5.0	4.0	5.0	5.5	5.0	5.0	5.0	5.5
2.600	4.5	5.0						
3.900	–	–						

Test #5 Buffed Aluminum

	Percent Reflectance			
Wavelength (Micron)	Sample 1	Sample 2	Sample 3	Sample 4
0.295	57.5			
0.330	66.0			
0.355	67.5	70.5	70.0	63.5
0.377	69.5			
0.400	71.0			
0.415	71.5			
0.430	72.0			
0.445	73.0	74.5	73.5	68.0
0.458	73.0			
0.470	73.5			
9.484	73.5			
0.497	74.0			
0.511	74.0	76.0	74.5	70.0
0.526	74.0			
0.540	74.5			
0.554	75.0			
0.569	75.0			
0.584	75.0	76.0	75.0	71.0
0.598	75.0			
0.614	75.5			
0.630	75.5			
0.646	75.0			
0.664	74.0	75.5	75.0	71.5
0.681	73.5			
0.700	71.5			
0.718	73.0			
0.738	73.0			
0.759	74.0	75.0	72.0	70.0
0.781	73.0			
0.804	73.0			
0.828	73.5			
0.853	72.5			
0.880	74.0	75.5	74.0	71.0
0.910	76.0			
0.940	78.5			
0.974	80.0			
1.011	81.5			
1.052	82.0	81.5	77.5	80.0
1.096	83.0			
1.148	83.5			
1.200	84.0			
1.267	84.5			
1.341	85.5	85.5	85.5	83.0
1.428	88.0			
1.536	88.5			
1.671	87.5			
1.854	90.5			
2.120	91.0	91.5	90.0	90.0
2.600	93.5			
3.900	—			

Test #6 Vapor Deposited Aluminum Over Buffed Aluminum

	Percent Reflectance			
Wavelength (Micron)	Sample 1	Sample 2	Sample 3	Sample 4
0.295	72.0			
0.330	79.5			
0.355	82.0	82.5	80.0	78.5
0.377	84.0			
0.400	85.0			
0.415	85.5			
0.430	86.0			
0.445	87.0	86.0	85.5	84.5
0.458	87.5			
0.470	87.0			
0.484	87.5			
0.497	87.5			
0.511	88.0	87.0	87.0	86.5
0.526	88.0			
0.540	88.0			
0.554	88.5			
0.569	88.0			
0.584	88.0	88.0	88.0	87.5
0.598	88.0			
0.614	88.0			
0.630	88.0			
0.646	88.0			
0.664	87.5	88.0	87.5	86.5
0.681	87.5			
0.700	87.5			
0.718	87.0			
0.738	87.5			
0.759	86.5	87.0	87.0	86.0
0.781	86.5			
0.804	85.5			
0.828	85.0			
0.853	85.5			
0.880	86.0	85.5	86.0	85.5
0.910	87.5			
0.940	88.5			
0.974	90.5			
1.011	91.5			
1.052	93.5	93.5	94.0	93.5
1.096	93.5			
1.148	94.5			
1.200	95.0			
1.267	95.5			
1.341	95.5	96.0	96.0	96.0
1.428	96.0			
1.536	96.5			
1.671	96.5			
1.854	97.5			
2.120	98.0	97.5	97.5	98.0
2.600	100.0			
3.900	—			

Test #7 Gold Plate Over Buffed Aluminum

Wavelength (Micron)	Percent Reflectance						
	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Sample 6	Sample 7
0.295	–						
0.330	20.5						
0.355	23.5	28.0	29.0	29.0	28.5	28.5	29.0
0.377	25.5						
0.400	27.0						
0.415	27.5						
0.430	30.5						
0.445	31.0	30.5	31.5	31.0	31.0	30.5	30.5
0.458	31.5						
0.470	32.5						
0.484	35.5						
0.497	43.0						
0.511	51.5	51.5	52.0	54.5	55.0	53.5	54.5
0.526	61.0						
0.540	67.5						
0.554	72.5						
0.569	74.5						
0.584	80.0	80.5	80.5	83.0	83.5	83.0	83.5
0.598	81.5						
0.614	83.0						
0.630	85.0						
0.646	86.5						
0.664	88.0	87.5	88.0	90.0	90.5	90.0	90.5
0.681	89.5						
0.700	90.5						
0.718	90.5						
0.738	91.5						
0.759	92.0	92.0	93.0	94.5	94.5	93.5	95.0
0.781	92.5						
0.804	93.5						
0.828	93.5						
0.853	93.5						
0.880	94.5	95.0	95.0	96.0	96.5	96.0	96.5
0.910	95.0						
0.940	96.0						
0.974	95.0						
1.011	95.5						
1.052	96.0	96.0	96.5	96.5	97.0	97.0	97.0
1.096	96.5						
1.148	96.5						
1.200	96.5						
1.267	96.5						
1.341	97.0	97.0	97.5	97.5	97.5	97.0	97.5
1.428	97.0						
1.536	97.5						
1.671	97.0						
1.854	98.0						
2.120	98.0	98.0	98.5	98.5	98.5	98.5	99.0
2.600	100						
3.900	–						