N93-28270

SPECTRAL INFRARED HEMISPHERICAL REFLECTANCE MEASUREMENTS FOR LDEF TRAY CLAMPS

B. K. Cromwell
Sverdrup Technology Inc., AEDC Group
Arnold Air Force Base, TN 37389
Phone: 615/454-3478, FAX: 615/454-4913

Capt. S. D. Shepherd
USAF, Directorate of Technology
Arnold Air Force Base, TN 37389
Phone: 615/454-6517, FAX: 615/454-3559

C. W. Pender
Sverdrup Technology Inc., AEDC Group
Arnold Air Force Base, TN 37389
Phone: 615/454-4649, FAX: 615/454-4913

B. E. Wood
Calspan Corporation/AEDC Operations
Arnold Air Force Base, TN 37389
Phone: 615/454-7719, FAX: 615/454-6348

SUMMARY

This paper describes infrared hemispherical reflectance measurements that were made on 58 chromic acid anodized tray clamps from LDEF. The measurements were made using a hemiellipsoidal mirror reflectometer with interferometer for wavelengths between 2-15 μm. The tray clamps investigated were from locations about the entire spacecraft and provided the opportunity for comparing the effects of atomic oxygen at each location. Our results indicate there was essentially no dependence on atomic oxygen fluence for the surfaces studied, but there did appear to be a slight dependence on solar radiation exposure. The reflectances of the front sides of the tray clamps consistently were slightly higher than for the protected rear tray clamp surfaces.

INTRODUCTION

The Long Duration Exposure Facility (LDEF) spent 5 years and 10 months in space. The experiments and materials on board have provided a wealth of data for determining long-term effects of space on materials. Many measurements have been made on the various samples and surfaces returned to determine sources and effects of the contaminants that were experienced.

The measurements described herein were funded through the Office of the Secretary of Defense Central Test and Evaluation Investment Program - Project on Space Systems Aging Study (DD29) and Wright Laboratory Project DB72 for Surface Effects of Contamination.

This paper describes measurements that were made on 58 chromic acid anodized tray clamps removed from LDEF that were used for maintaining the experiments in place. Spectral infrared reflectance measurements were made for the clamps that were located in various positions about the spacecraft. These clamps were located externally and were used to hold the experiments in place. The reflectances of the front surfaces of the clamps were measured to determine the variation in surface contaminant with satellite location. Reflectance measurements of the rear surfaces for the clamps were made to provide a clean reference surface of the same material that was not externally exposed to space. Changes in reflectance of the tray clamps have been compared to atomic oxygen fluences (atoms/cm2) incident at those locations. No correlation was observed. A decrease in infrared absorption for absorption bands near 2.9 and 6.2 μm was observed for the surfaces exposed to space, indicating that there was some surface change in the outer layer of the chromic acid anodized material. In all of the surfaces measured no evidence of contamination was observed from the spectral reflectance measurements made, and none of the samples showed evidence of the brown so-called "nicotine" stain that has been seen so prominently in other experiments.

Total emittance values (for an angle of 15 deg from the surface normal) were calculated for both the exposed (front side) and unexposed (back side) tray clamp surfaces. Only small differences (average of about 1 percent) were observed. The surface exposed to space generally exhibited an overall decrease in emittance (reflectance increase) as compared to the back side (shielded) of the tray clamp. The average change in emittance of the clamps located on the space end of the satellite was about a factor of 2 greater than the average for the other locations. The space end received the greatest amount of solar flux. It appears that for these clamps the solar incident flux had a greater effect on the emittance than did the atomic oxygen fluence.

REFLECTANCE MEASUREMENTS DESCRIPTION

It wasn't known beforehand whether the samples would reflect specularly or diffusely. Therefore, a technique for measuring combined specular and diffuse components was employed. An ellipsoidal mirror reflectometer approximately 12 in. in diameter (Ref. 1) was used for making the hemispherical reflectance measurements (Fig. 1). The reflectance measurement technique was improved through the use of a Fourier transform scanning (FTS) interferometer which allowed reflectance measurements to be made in a more timely fashion than was accomplished in Ref. 1 (Fig. 2). The ellipsoidal mirror is ground such that the two foci are located on the major axis (y axis in Fig. 1) and are separated by 2 in. At one focus, a blackbody is located to provide the diffuse hemispherical radiance. This radiation is collected by the hemiellipsoidal mirror and is focused at the second ellipsoid focus where the sample is located. The radiation emitted by the blackbody (temperature = 350°C) is chopped at a rate of approximately 0.5 Hz. The slow chopping rate allows the interferometer to scan the radiation reflected and emitted from the sample while the chopper is in the open position and only the emitted radiation from the sample when the chopper is in the closed position. By subtracting these two values, a signal is obtained that is proportional to the sample reflected radiation. The interferometer views the sample through a hole in the mirror which is centered at an angle of 15 deg from the sample normal. After the reflected radiation from the test sample is measured, the tray clamp is then replaced with a gold mirror (reflectance ~ 0.98) and the measurements repeated. The tray clamp reflectance is determined by ratioing the sample signal to that obtained for the gold reference mirror since its reflectance is near unity.

The Fourier transform spectrometer used was a Block Model 197RS Michelson-type interferometer. The resolution used was 8 cm^{-1}. The FTS scan rate was synchronized with the chopper such that 20 scans were recorded for the chopper in the open position and then 20 scans when the chopper was in the closed position. The Fourier transform was executed after all of the 20 scans were coadded for each case. Measurements were made for both the tray clamp and the gold reference surface and the output values at each wavelength were ratioed to obtain the tray clamp spectral reflectance.

DESCRIPTION OF SAMPLES AND LDEF LOCATIONS

The samples consisted of 58 tray clamps which were taken from more than 700 total clamps on LDEF. The clamps were made of chromic acid anodized (CAA) aluminum. Measurements on other tray clamps have been previously investigated (Refs. 2-5). The locations of the samples on LDEF that were investigated in this study are listed in Table 1 and are shown in Fig. 3 for both forward and rear views of the LDEF satellite. In Fig. 3 the locations of the tray clamps used in this study are indicated by the dots at the various bay and row locations. In Table 1 the sample locations on the trailing edge (Rows 1-4) are listed. Similarly, rows 5-6 and 11-12 are grouped for the side locations, and rows 7-10 list the samples in the forward moving (ram) direction. Samples on the earth end of the satellite (Bay G) and for the space viewing end (Bay H) are also shown. The locations given in Table 1 are grouped in the same manner as for the reflectance data, which will be shown later.

RESULTS

Reflectance measurements were made on the LDEF tray clamps after they had been retrieved from space. Measurements were made on the front surface (exposed to space) and back surface (shielded from space effects) for each tray clamp. The reflectance data are shown in Figs. 4-10. The data have been grouped to include data from relatively high atomic oxygen incidence rate (Fig. 4) for all bay locations in rows 7-10, the lowest atomic oxygen rates (Fig. 5) for all bays in rows 1-4, for intermediate atomic oxygen rates for bays in rows 5,6 (Fig. 6) and in rows 11-12, (Fig. 7), and for trays located on the earth (G bay) and space (H bay) ends (Figs. 8-9). The atomic oxygen fluences are those provided in Ref. 3 (also presented in Table 2). The atomic oxygen fluence levels for rows 1-4 varied from 1.13E+03 up to 2.27E+17; for rows 5-6, 11-12 the levels varied from 3.73E+12 up to 5.43E+21; for rows 7-10, the levels varied from 1.12E+21 up to 8.74E+21; and for the earth and space ends, the levels were 3.05E+20 and 4.27E+20, respectively. There is some overlap in fluence levels between the 5-6, 11-12 category and the 7-10 category.

All reflectance curves for the 58 samples front and rear surfaces exhibited essentially the same spectral features which evidently are a result of the anodizing process. The major absorption band is located at 2.9 to 3.0 μm, and the depth of this band varied considerably from clamp to clamp for both exposed and shielded surfaces. A weak absorption band is sometimes seen at 3.4 um and a relatively strong band appears in the 6.1- to 6.2-μm region. A shoulder in the reflectance curves is seen centered at approximately 9.0 μm and is followed by a broad spectral feature centered about 10.8 to 11.0 μm. The spectral feature at 4.3 um should be ignored, since this is caused by the variation in CO_2 concentration in the radiation path from measurement to measurement.

Figure 10 shows direct comparisons of the front and back surfaces for samples F02-1, D07-4, C06-7, and B12-1 which were typical samples from the trailing edge, side edges, and leading edge, respectively. Similarly, Fig. 11 shows comparisons of front and back sides of samples taken from the earth (Bay G) and space (H) viewing ends of LDEF. In comparing the results between the front surfaces and back surfaces for the same tray clamp, the major differences are seen in the depths of the absorption bands located in the vicinity of 6.1 μm. This band is believed to be a C=O band, which is a carbonyl band. In nearly all cases, the depth of this band is less for the front surface than for the rear surface. This indicates that the source for this absorption band is being removed as a result of its location on an exterior surface. This may be due to a reduction in the anodize film layer thickness as suggested in Ref. 2, or some form of bleaching mechanism. One interesting point is that there is no observable difference seen between the front and rear surface when the four categories of atomic oxygen fluences are considered. Even for the lowest atomic oxygen fluence levels, rows 1-4, (down by at least 16 orders of magnitude) it is seen that the 6.1-μm band has been reduced on the front surface. The C-H hydrocarbon band at 3.4 μm similarly is observed to be eliminated or reduced in intensity for the front surfaces, as compared to the rear surfaces. Again, this is observed for all row categories regardless of atomic oxygen fluence level.

The surfaces that showed the most spectral structure are the rear (or shielded) tray clamp surfaces indicating that essentially all of the spectral features seen were due to the anodizing process used in preparing the clamps. No evidence was seen on the external surfaces of the clamps of space-deposited silicones or hydrocarbon contaminants. Visually, all of the clamps appeared the same for both front (exposed) and rear (shielded) surfaces. None of the so-called "nicotine" brown stain or other forms of contaminant reported in Ref. 4-5 was observed on any of the clamps.

Effect of Space Exposure on Tray Clamp Emittance

To determine emittance effects, the total (wavelengths) emittance, $E(\theta = 15°)$ was determined for an incidence or view angle (θ) of 15 deg. The spectral emittance values (E_λ) were determined by subtracting the spectral reflectivity values from one, since $E_\lambda(\theta = 15°) = A_\lambda(\theta = 15°)$ where $A_\lambda(\theta = 15°)$ is the spectral absorptivity.

$$E_\lambda(\theta = 15°) = A_\lambda(\theta = 15°) = 1 - R_\lambda(\theta = 15°) \qquad (1)$$

The spectral emittances measured were used with the blackbody emission curve for a temperature of 300 K, $B_\lambda(T = 300\text{ K})$ to determine the total emittance for each of the 58 samples, both front and rear surfaces. The expression used for calculating emittance is

$$E(\theta = 15°) = \frac{\int_{2.5}^{15.0} E_\lambda(\theta = 15°)\, B_\lambda(T = 300\text{ K})\, d\lambda}{\int_{2.5}^{15.0} B_\lambda(T = 300\text{ K})\, d\lambda} \qquad (2)$$

The emittance values determined for all the surfaces measured are shown in Table 2 and are presented in **order of decreasing atomic oxygen fluence**. The atomic oxygen and sun exposure levels were taken from Ref. 6. By averaging all the emittance values for both front and back surfaces, it was found that the exposed surface emittance, at 15 deg from the surface normal, was 0.185 and the rear (shielded) surface was 0.197. This yields an average difference of (0.012) in emittance between front and back surfaces. In the LDEF Interim Report (Ref. 3) it is reported that only slight changes were observed in the ratio of the solar absorptance to surface emittance (a/e). At that time it was unknown if the changes were due to contamination or surface erosion. From the results of this investigation it would appear the change in a/e ratio is due more to surface change than deposition of contaminants. The changes observed indicate that the space-exposed surface reflectances of the clamps are increased, thereby decreasing the surface emittances. This, then, would cause an increase in the a/e ratios. This behavior, in principle, is consistent with the findings of Ref. 2 which reported a/e increases from 1 to 6 percent, depending on the clamp location. They reported that the largest change in a/e was observed on the space end (H bay).

The average change in emittance is calculated for each of the four atomic oxygen ranges presented in Table 2. There were 20 samples in the predominantly forward moving direction (Rows 7-12) where the atomic oxygen fluence was greater than 1×10^{21} atoms/cm2 and 15 samples on the predominantly trailing rows (1-6) where the AO fluence varied between 9×10^4 and 3.9×10^{19}. The other sample locations were 11 on the space end (H bay) and 12 on the earth end (G bay) where the AO fluence was on the order of 10^{20}. The change in average emittance between front and rear surfaces for the space end clamps is seen to be 0.022, which is about double that for the entire spacecraft. The space end also received the greatest amount of sunlight (see Table 2) and apparently the sunlight affected the tray clamp emittances more than did the atomic oxygen. This trend was also observed in Ref. 2. However, the reflectance/emittance measurement uncertainty for the present study was ± 1 percent, which means the changes measured may not be statistically significant.

SUMMARY

Hemispherical infrared (2.5 to 15.0 μm) reflectance measurements have been made on 58 LDEF tray clamps after retrieval from 5 years and 10 months in space. These clamps were located externally and were used to hold the experiments in place. The reflectances of the front surfaces of the clamps were measured to determine the variation in surface contaminant with satellite location. Reflectance measurements of the rear surfaces for the clamps were made to provide a clean reference surface of the same material but not externally exposed to space. The reflectance measurements were made using a scanning interferometer with an ellipsoidal mirror reflectometer.

The results of this investigation show only slight differences between the exposed surfaces of the tray clamps and the shielded surfaces. Some evidence of surface cleaning was observed with absorption band intensities at 2.9 and 6.1 being reduced for the exposed surfaces. This cleaning didn't appear to be a strong function of the surface location relative to the ram direction and hence appeared to be independent of atomic oxygen fluence level.

Total emittances were determined for the individual tray clamp surfaces for a temperature of 300 K. The average emittance for the surfaces exposed to space was 0.185 and was 0.197 for the side that was shielded from space. This indicated a slight "cleaning" of the clamps exposed to space. The average difference in emittance for the front and rear

surfaces was −0.012 and agrees with the findings of Ref. 2. This change in emittance may have been a stronger function of sunlight hours than atomic oxygen exposure.

Overall, the relatively small changes observed in infrared reflectance and emittance of the chromic acid anodized aluminum surfaces for the 5 years + in space should be pleasing to designers who are considering the use of similar material for the Space Station Freedom.

REFERENCES

1. Wood, B. E., Pipes, J. G., Smith, A. M., and Roux, J. A., "Hemi-ellipsoidal mirror infrared reflectometer: development and operation," Applied Optics, Vol. 15, No. 4, April 1976, pp. 940-950.

2. Plagemann, Walter L., "Space Environmental Effects on the Integrity of Chromic Acid Anodized Coatings", NASA CP-3134 (Part 2), "LDEF -- 69 Months in Space", 1991, pp. 1023-1040.

3. Systems Special Investigation Group, Long Duration Exposure Facility, Interim Report, January 1991.

4. LDEF Materials Special Investigation Group (Bland Stein - Chairman), "Preliminary Report on LDEF-Related Contaminants," August 1990.

5. Crutcher, E.R. and Warner, K. J., "Molecular Films Associated With LDEF," NASA CP-3134 (Part 1), "LDEF -- 69 Months in Space," First Post-Retrieval Symposium, 1991, pp. 155-177.

6. Bourassa, Roger J., Gillis, James R., and Rousslang, K. W., "Atomic Oxygen and Ultraviolet Radiation Mission Total Exposures for LDEF Experiments," NASA Report Number 3134 - Part 2, "LDEF -- 69 Months in Space," First Post-Retrieval Symposium, 1991, pp. 643-662.

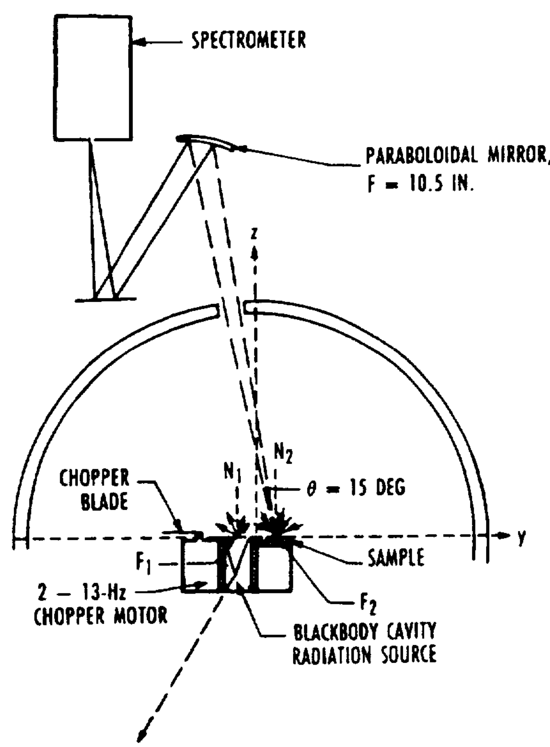

Figure 1. Experimental arrangement of hemiellipsoidal mirror reflectometer.

C-4

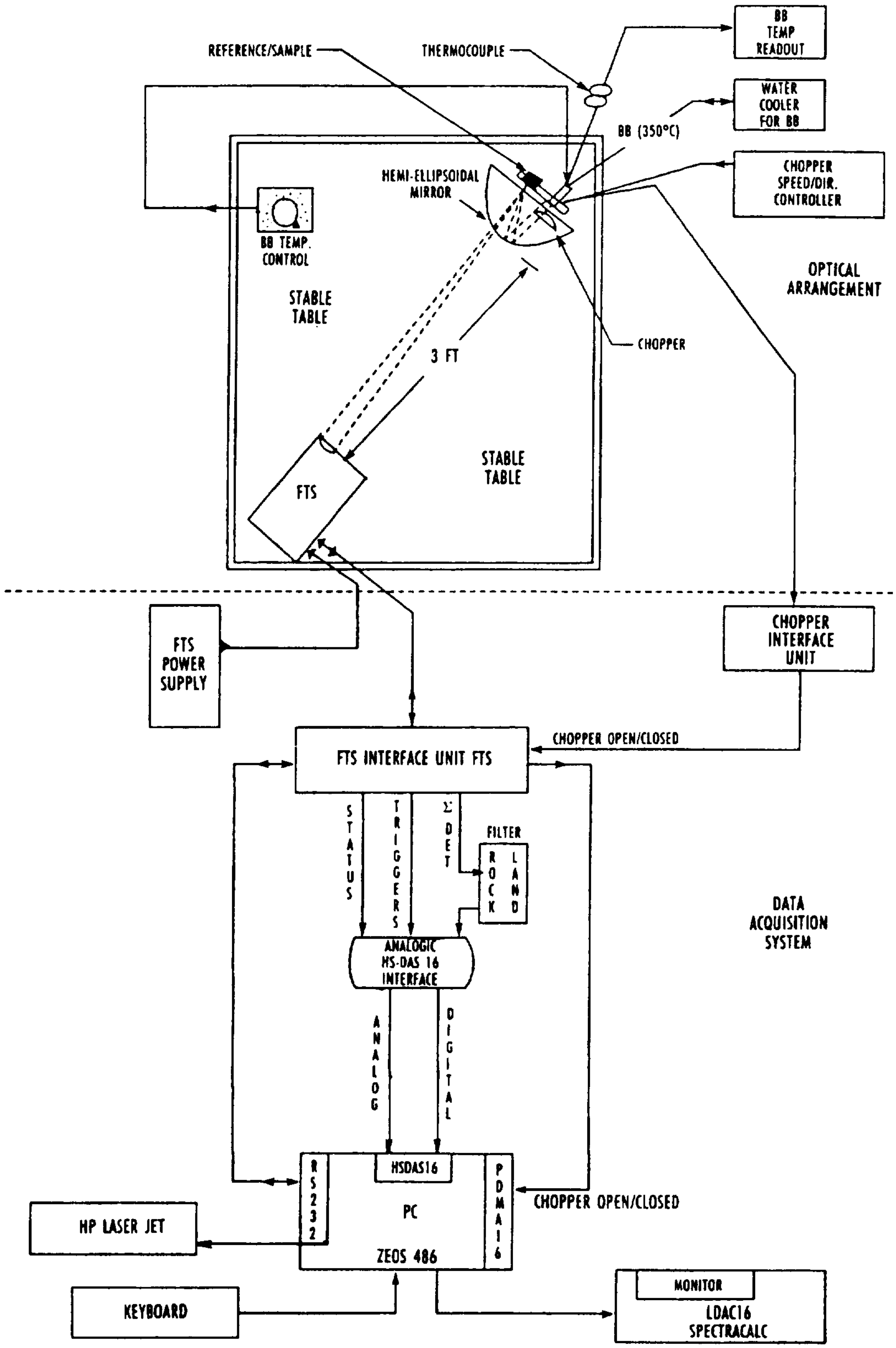

Figure 2. FTS interferometer interfaced with hemiellipsoidal mirror reflectometer.

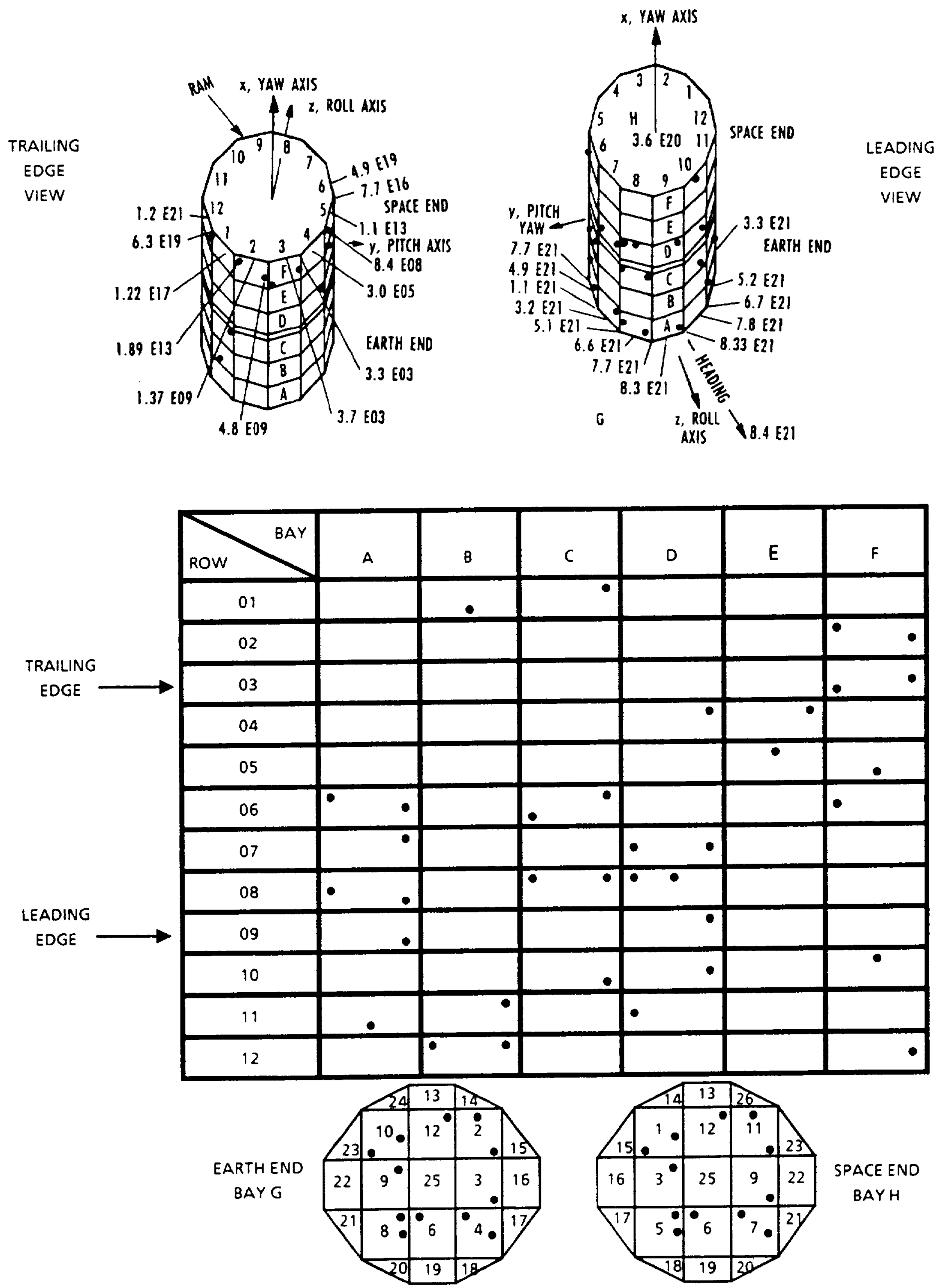

Figure 3. Location of LDEF tray clamps.

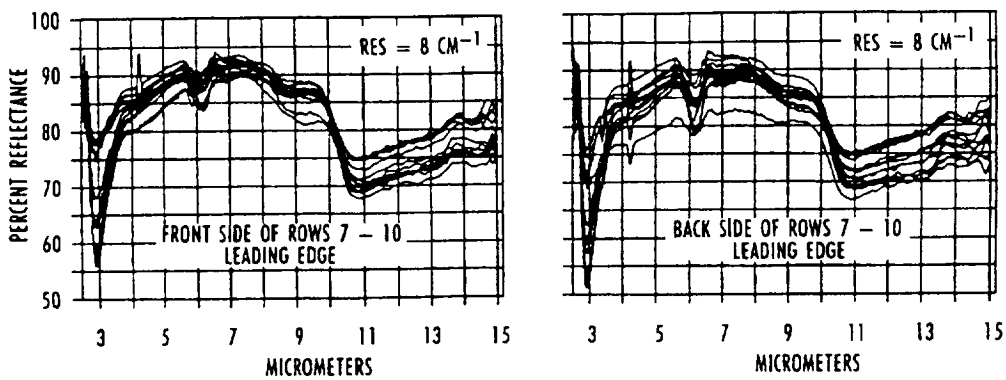

Figure 4. Tray clamp spectral reflectance, rows 7 - 10.

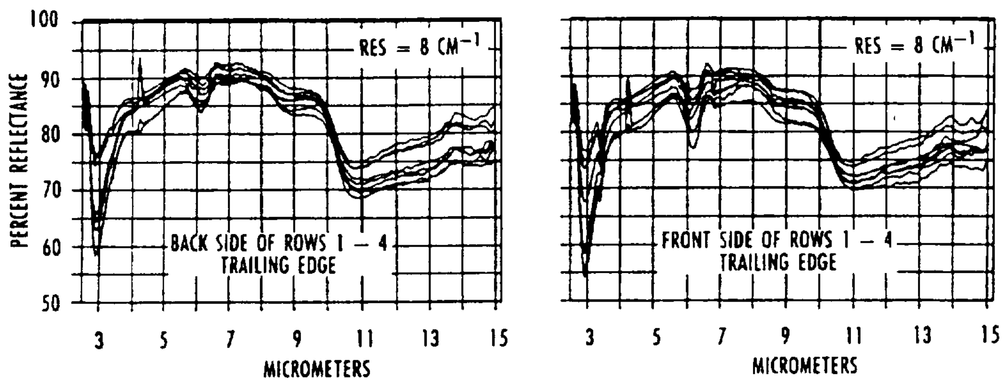

Figure 5. Tray clamp spectral reflectance, rows 1 - 4.

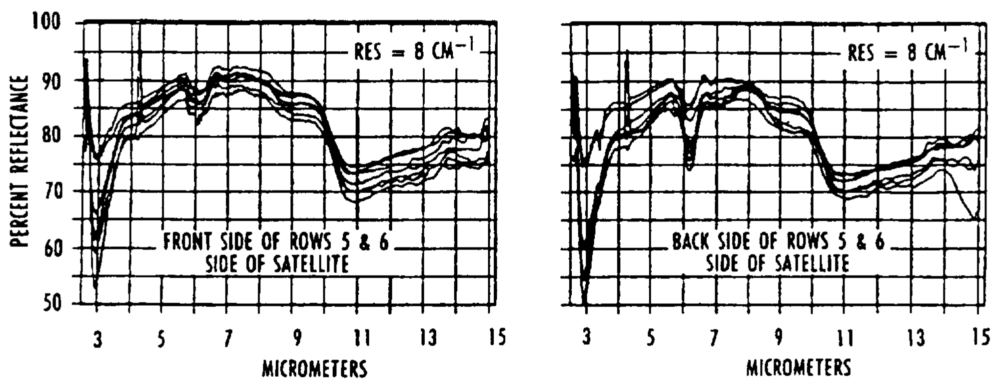

Figure 6. Tray clamp spectral reflectance, rows 5 - 6.

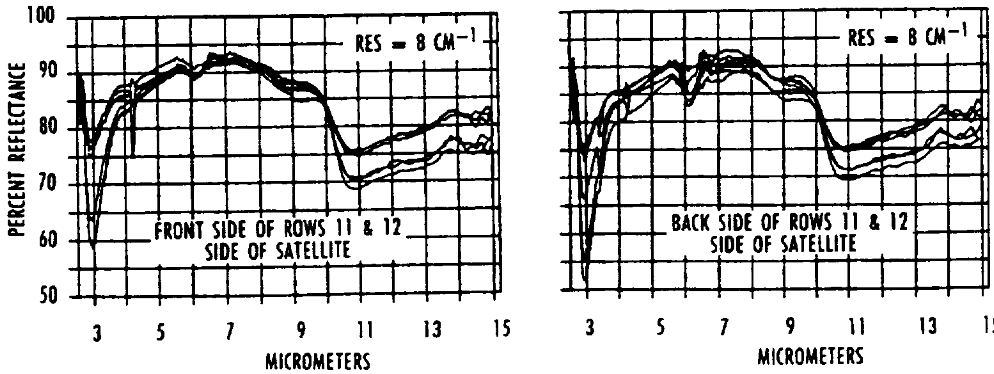

Figure 7. Tray clamp spectral reflectance, rows 11 - 12.

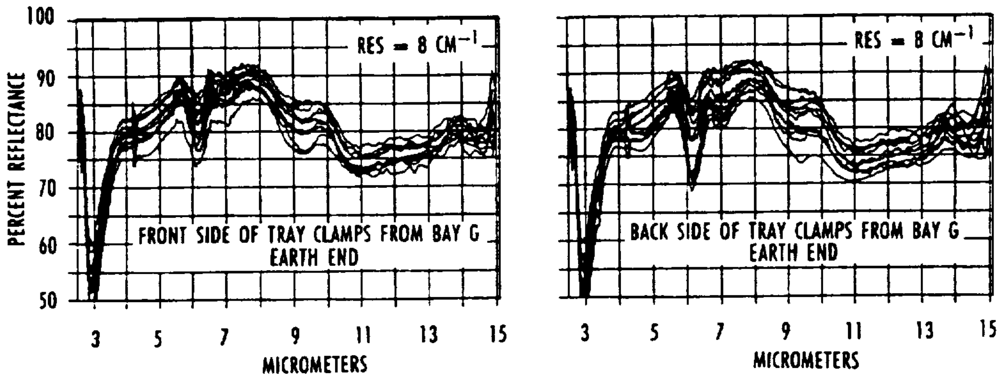

Figure 8. Tray clamp spectral reflectance, earth end.

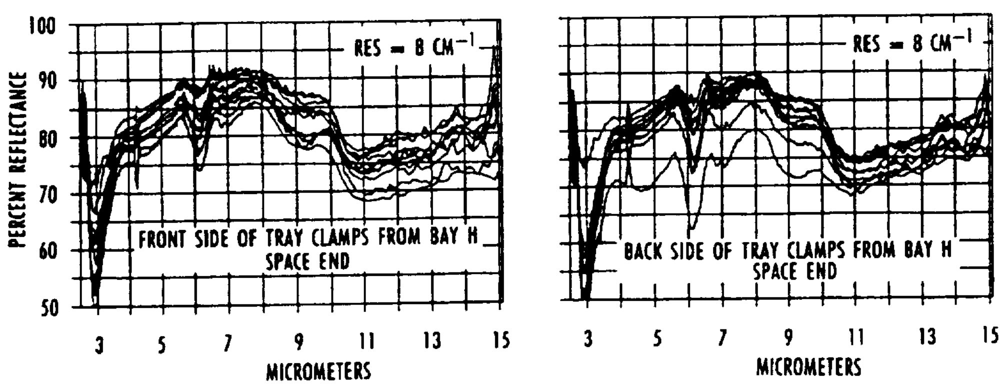

Figure 9. Tray clamp spectral reflectance, space end.

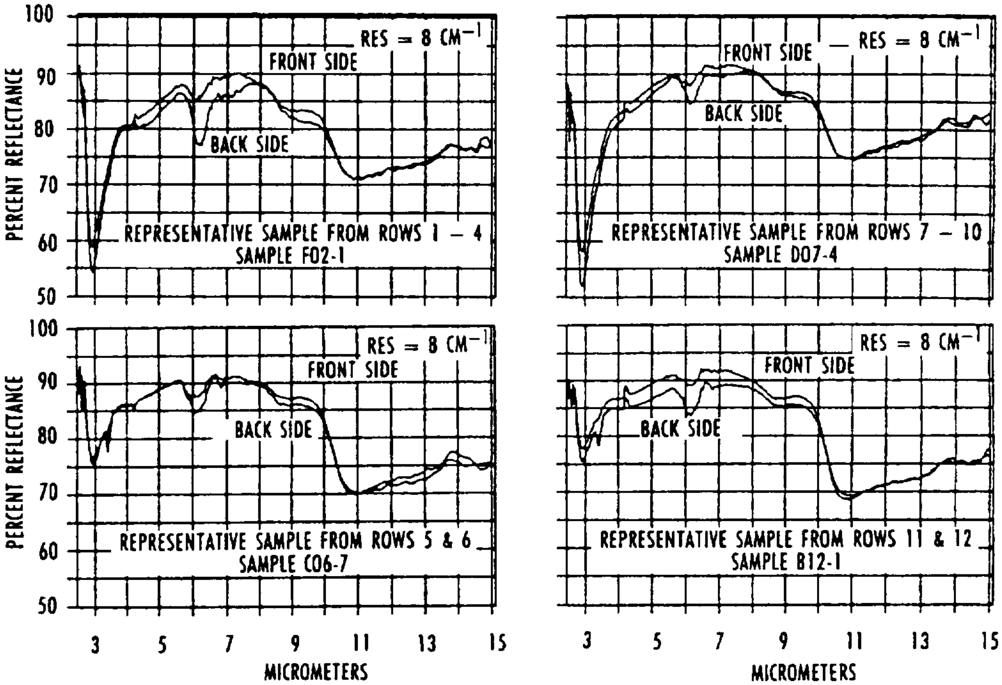

Figure 10. Comparisons of front and back surfaces for tray clamps located on leading edge, trailing edge, and sides of LDEF.

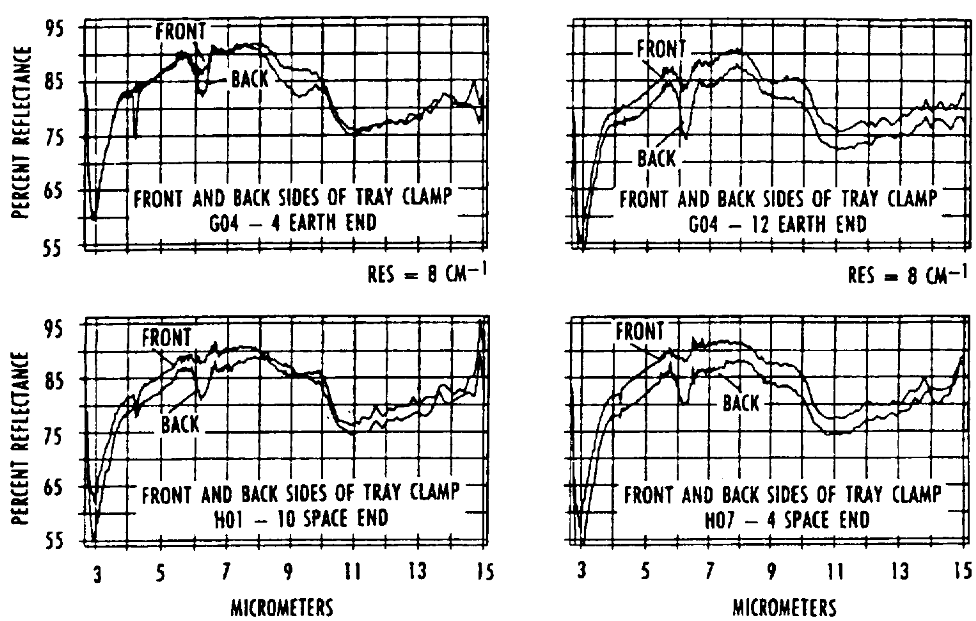

Figure 11. Comparisons of front and back surfaces for tray clamps located on space and earth viewing ends of LDEF.

Table 1. Locations of LDEF Tray Clamps

ROW 1-4	ROWS 5-6, 11-12	ROW 7-10	EARTH END	SPACE END
B01-6	A06-1	A07-3	G02-2	H01-5
C01-3	A06-4	A08-5	G02-7	H01-10
D04-3	A11-6	A08-8	G04-4	H03-4
E04-3	B11-3	A09-5	G04-10	H05-3
F02-1	B12-1	C08-1	G04-12	H05-5
F02-4	B12-3	C08-3	G06-3	H06-1
F03-4	C06-3	C10-5	G06-6	H07-1
F03-7	C06-7	D07-4	G08-3	H07-4
	D11-8	D07-8	G08-11	H09-7
	E05-2	D08-1	G10-1	H11-2
	F05-6	D08-2	G10-8	H12-4
	F06-8	D09-3	G12-7	
	F12-4	D10-4		
		F10-2		

Table 2. Total Emittance Values of LDEF Tray Clamps at 300 K and Atomic Oxygen Fluence (atoms/cm^2) Levels and Equivalent Sun Hours (Listed in order of Atomic Oxygen Fluence)

SAMPLE NO.	EMITTANCE FRONT	EMITTANCE BACK	EMITTANCE DIFF. (f-b)	AO FLUENCE*	SUN HOURS*
ROWS 7-12					
A09-5	0.208	0.205	+ 0.003	8.72E21	11,200
D09-3	0.205	0.203	+ 0.002	8.72E21	11,200
C10-5	0.194	0.199	− 0.005	8.17E21	10,700
D10-4	0.162	0.170	− 0.008	8.17E21	10,700
F10-2	0.172	0.166	+ 0.006	8.17E21	10,700
A08-5	0.204	0.199	+ 0.005	6.93E21	9,400
A08-8	0.161	0.170	− 0.009	6.93E21	9,400
C08-1	0.182	0.245	− 0.063	6.93E21	9,400
C08-3	0.173	0.172	+ 0.001	6.93E21	9,400
D08-1	0.198	0.211	− 0.013	6.93E21	9,400
D08-2	0.162	0.175	− 0.013	6.93E21	9,400
A11-6	0.158	0.166	− 0.008	5.43E21	8,500
B11-3	0.180	0.184	− 0.004	5.43E21	8,500
D11-8	0.165	0.181	− 0.016	5.43E21	8,500
A07-3	0.189	0.212	− 0.023	3.28E21	7,100
D07-4	0.165	0.172	− 0.007	3.28E21	7,100
D07-8	0.173	0.200	− 0.027	3.28E21	7,100
B12-1	0.194	0.203	− 0.009	1.28E21	6,800
B12-3	0.185	0.179	+ 0.006	1.28E21	6,800
F12-4	0.162	0.171	− 0.009	1.28E21	6,800
			AVG. − 0.01		
SPACE END					
H01-5	0.159	0.182	− 0.023	4.27E20	14,500
H01-10	0.158	0.180	− 0.022	4.27E20	14,500
H03-4	0.203	0.272	− 0.069	4.27E20	14,500
H05-3	0.200	0.210	− 0.010	4.27E20	14,500
H05-5	0.208	0.243	− 0.035	4.27E20	14,500
H06-1	0.208	0.208	0	4.27E20	14,500
H07-1	0.187	0.187	+ 0.003	4.27E20	14,500
H07-4	0.153	0.153	− 0.033	4.27E20	14,500
H09-7	0.215	0.215	+ 0.014	4.27E20	14,500
H11-2	0.190	0.190	0	4.27E20	14,500
H12-4	0.169	0.169	− 0.064	4.27E20	14,500
			AVG. − 0.022		

NOTES: *Ref. 6 — Bourassa and Gillis

Table 2. Concluded.

SAMPLE NO.	EMITTANCE FRONT	EMITTANCE BACK	EMITTANCE DIFF. (f-b)	AO FLUENCE*	SUN HOURS*
EARTH END					
A09-5	0.197	0.193	+ 0.004	3.05E20	4,500
D09-3	0.171	0.159	− 0.012	3.05E20	4,500
C10-5	0.174	0.164	+ 0.010	3.05E20	4,500
D10-4	0.194	0.194	0	3.05E20	4,500
F10-2	0.175	0.210	− 0.035	3.05E20	4,500
A08-5	0.217	0.241	− 0.024	3.05E20	4,500
A08-8	0.178	0.188	− 0.010	3.05E20	4,500
C08-1	0.164	0.159	+ 0.005	3.05E20	4,500
C08-3	0.222	0.215	+ 0.007	3.05E20	4,500
D08-1	0.208	0.218	− 0.010	3.05E20	4,500
D08-2	0.198	0.213	− 0.015	3.05E20	4,500
A11-6	0.212	0.216	− 0.004	3.05E20	4,500
			AVG. − 0.01		
ROW S1-6					
A06-1	0.211	0.231	− 0.020	3.89E19	14,500
A06-4	0.182	0.201	− 0.019	3.89E19	14,500
C06-3	0.207	0.193	+ 0.014	3.89E19	14,500
C06-7	0.190	0.198	− 0.008	3.89E19	14,500
F06-8	0.164	0.192	− 0.028	3.89E19	14,500
B01-6	0.156	0.207	− 0.051	2.27E17	14,500
C01-3	0.187	0.189	− 0.002	2.27E17	14,500
F02-1	0.200	0.211	− 0.011	1.54E17	14,500
F02-4	0.166	0.178	− 0.012	1.54E17	14,500
F03-4	0.170	0.163	+ 0.007	1.32E17	14,500
F03-7	0.196	0.198	− 0.002	1.32E17	14,500
E05-2	0.170	0.191	− 0.021	3.73E12	14,500
F05-6	0.188	0.204	− 0.016	3.73E12	14,500
D04-3	0.204	0.205	− 0.001	9.32E04	14,500
E04-3	0.201	0.205	− 0.004	9.32E04	14,500
			AVG. − 0.01		
AVERAGE	**0.185**	**0.197**	**− 0.012**		

NOTES: *Ref. 6 — Bourassa and Gillis