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LDEF ATOMIC OXYGEN FLUENCE UPDATE*

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INTRODUCTION

The definition of LDEF atomic oxygen exposure involves theoretical prediction of fluxes, modeling of shielding and scattering effects, and comparison of predicted with observed atomic oxygen effects on LDEF experiments. Work is proceeding as follows: atomic oxygen fluxes and fluences have been recalculated using a more detailed orbit prediction program; a micro-environments program is being developed to account for the effects of experiment geometry on atomic oxygen flux; and, chemical and physical measurements are being made on copper grounding straps to verify correspondence between predicted exposures and observed surface property variations. These three areas of work are reported briefly herein.

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LDEF ATOMIC OXYGEN FLUENCE UPDATE, AO FLUENCE CALCULATION

Atomic oxygen fluxes and fluences for LDEF have been recalculated using a more accurate procedure for establishing orbit altitude. The calculation reported at the First LDEF Post-Retrieval Symposium, Reference (1) was based on altitudes determined by way of a point-mass, elliptical-orbit routine assuming a spherical earth. These simplifying assumptions could introduce error in the calculated atomic oxygen environment. Atomic oxygen flux calculations are very sensitive to altitude accuracy.

Both the original calculation and the refined calculation are based on state vectors prepared, courtesy of Cheryl Andrews of NASA Johnson Space Center, from NORAD elements which are in turn based on ground observations of LDEF recorded during the mission. The refined calculation was made using a Long Term Earth Satellite Orbit Prediction Program to determine orbit position and orbit average conditions between tabulated state vectors. The general course of calculation was to start at a state vector and then continue with simple adjustments to drag coefficient to minimize differences between calculated and observed positions of the spacecraft. Once significant error developed, the calculation was restarted using a later state vector as the starting position. Twenty-one such spans of calculation were needed to cover the LDEF mission. Calculated orbital data were tabulated for 5.75-minute intervals for the mission. In the original calculation, orbit average flux was determined from the first sixteen orbits following each state vector. The principal features of orbit calculation are summarized in Figure 1.

The method of determining atomic oxygen fluxes from the orbital data is unchanged from the method reported earlier, Reference (1).

ORBITAL MECHANICS

- Eighth order gravitational harmonics
- Perturbations of sun and moon
- Atmospheric drag
- Daily observed solar activities

MISSION TREATMENT

- Calculation spans: twenty-one ranging from 381 days to 11 days duration
- Position and velocity vectors: tabulated at 5.75-minute intervals for the mission
- Drag coefficient: adjusted to match calculated with reported state vectors
- Standard deviation of altitude (calculated with observed), 103 points: 0.61 km
- Mean altitude error, 103 points: -0.13 km

ATOMIC OXYGEN MODEL (Unchanged)

- Thermal molecular velocity: kinetic theory treatment
- Atmospheric Model: NASA MSIS-1986
- Atmospheric velocity: co-rotation of earth's atmosphere
- Outputs: flux and mission total fluence for each tray and longeron

Figure 1. Features of the LDEF atomic oxygen exposure calculation.

LDEF ATOMIC OXYGEN FLUENCE UPDATE, AO FLUENCE CALCULATION

The results of the revised calculation are summarized in Figure 2. The revised calculation found ram direction fluence to be 4.3% greater than that reported initially. However, this value is an average difference for the entire mission. Fluences for shorter periods of time differ by as much as 18% between the two calculations. The difference could be significant for experiments that were not open for the entire fight. The results of the revised calculation should be used for LDEF materials evaluations.

Fluences for trailing surfaces show a relatively greater difference between calculations. The revised calculation gives lower values than the original calculation, for example: the fluence for Row 3 was calculated originally as 3.71E03 atom/sq cm compared with a revised value of 1.33E03 atoms/sq cm. The difference is attributed to a small difference in average atmospheric temperature between the two determinations of orbit altitude. However, fluences on trailing surfaces are shown to be insignificant by either calculation at angles greater than about 105 degrees to ram. The data reported in Figure 2 are for the free, orbital flight of LDEF. They do not include exposure of the vehicle during or after retrieval.

The revised calculation incorporates the best information available on pitch and yaw angles as determined by Dr. Bruce Banks, NASA Lewis Research Center (Reference 2). The yaw angle is 8.1 degrees with the spacecraft turned so that the ram direction lies between Rows 9 and 10. Pitch angle is 0.8 degree with the space end of the vehicle pitched forward. The 0.8-degree forward pitch causes a significant difference between space-end and earth-end atomic oxygen exposures.

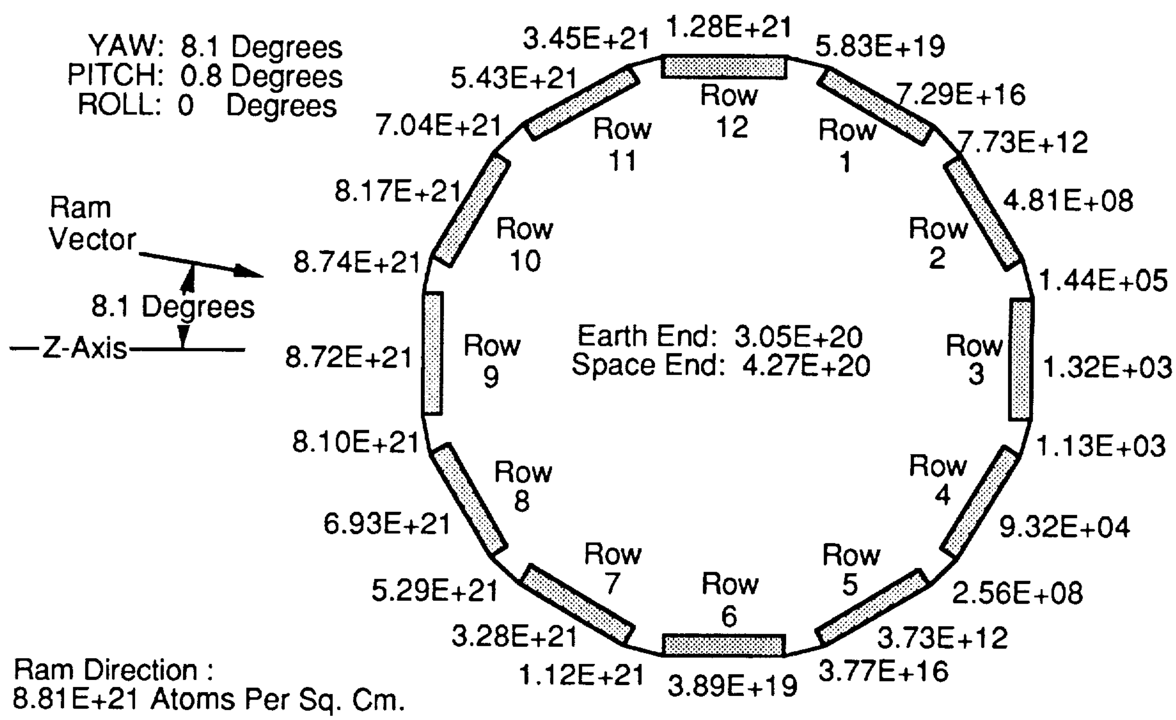

Figure 2. Revised atomic oxygen fluences for LDEF at the end of orbital flight. Fluences incurred during retrieval are not included in the totals shown.

LDEF ATOMIC OXYGEN FLUENCE UPDATE,
AO MICROENVIRONMENTS PROGRAM

A microenvironments program is being developed to handle the effects of shadowing, scattering and reflection of atomic oxygen from objects near an exposed area of a spacecraft. Thus far, a program has been developed using available routines to account for shadowing. The general layout of the program is shown in Figure 3. A geometric routine is used to describe the shape and arrangement of hardware items in numerical terms. A ray tracing routine is used to determine the field of view for selected points on an experiment. Flux intensity as a function of direction is determined and intensity is summed over the field of view to yield total flux. The calculation is repeated for other points. Pictorial and graphical presentations of atomic oxygen exposure for the experiment are generated from the geometric inputs and calculated fluxes.

Scattering and reflection routines will be added to the program described. The program developed thus far is computationally efficient. About one minute of machine time is required per one hundred points of calculation.

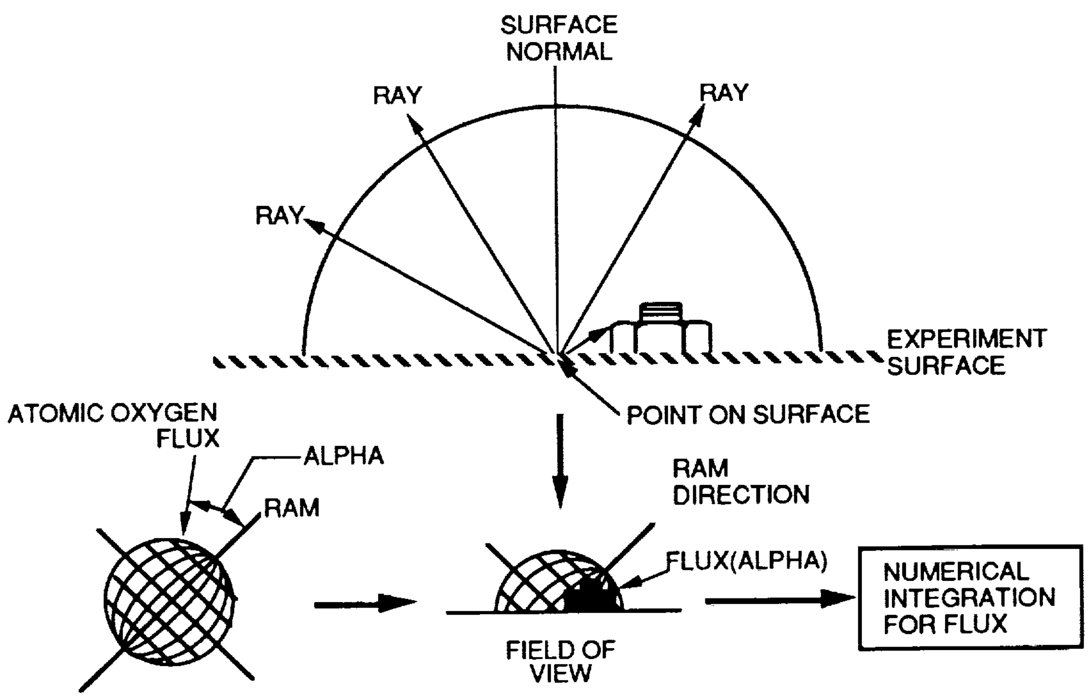

Figure 3. The field of view from a point on the spacecraft surface is obstructed by a fastener.

LDEF ATOMIC OXYGEN FLUENCE UPDATE, AO MICROENVIRONMENTS PROGRAM

Figure 4 shows the results of a preliminary calculation made with the microenvironments program. For trial calculation purposes, an experiment tray with simple geometry was assumed. The tray shown is three inches deep. Lateral tray dimensions are 46" x 34". A 12-inch diameter cylinder, 4.5 inches in height is attached to the bottom of the tray. The tray is positioned so that the viewer faces the 34-inch wide end of the tray. The angle between ram vector and the normal vector is 38 degrees. Atmospheric composition, temperature, and velocity were taken at average values for the LDEF flight.

The shadows on the bottom of the tray to the right of the cylinder show shielding caused by the cylinder. Lighter tones represent higher atomic oxygen fluxes. It will be noted that some shielding of the tray bottom is shown just upstream (left side) of the cylinder. This is because atomic oxygen arrives from all directions; thus the cylinder in fact causes some reduction in flux at the tray bottom even where the bottom surface is open to the ram direction. At the left edge of the tray, it can be seen that the vertical, 3-inch wall causes shielding of the bottom surface. The calculation is also valid for surfaces at any angle and for curved surfaces. Thus, the vertical surface at the right edge of the tray is shown to receive less flux than the vertical surface at the far end. The cylinder receives more flux on its left side (curved vertical surface) than on its right side. The flux on the cylinder cover is comparable to that at the tray bottom. The effects shown in Figure 4 are caused only by shadowing. The next step in the program development will be the addition of routines to handle scattering and reflection of incident atomic oxygen.

Figure 4 appears on the following page.

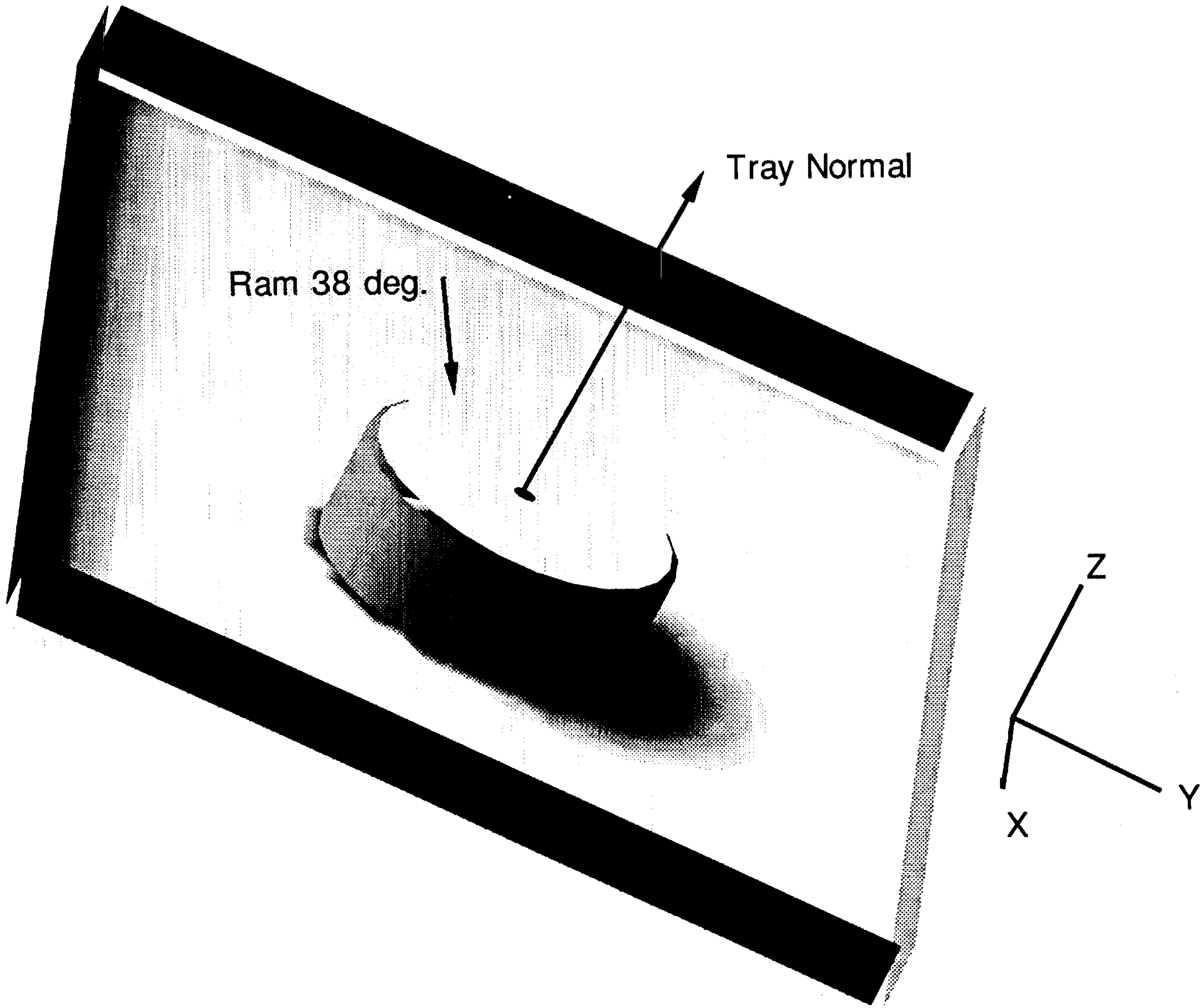

Figure 4. AO microenvironments checkout calculation using an assumed experiment configuration and average LDEF flight conditions.

Figure 5 illustrates how data generated with the microenvironments program can be used to analyze atomic oxygen exposures of complex surfaces. The variation of atomic oxygen flux on the cylindrical surface of the geometric model shown in Figure 4 is shown plotted as a function of angle in Figure 5. The values of flux used for the plot were taken on a line around the cylinder 2.25 inches above the tray bottom.The plot shows that atomic oxygen flux does not go completely to zero on the trailing side of the cylinder, although it declines very rapidly as angle is increased beyond about 100 degrees. This result agrees with results obtained previously with the analytical model.

The value of flux calculated by the microenvironments program for points on the tray bottom a few inches from the cylinder (3.64E13 atoms/cm2-sec) is in agreement with the average mission flux value for experiments on Row 8 of LDEF calculated by analytical integration of the flux equation for a plane surface. This result helps to validate the numerical integration routine.

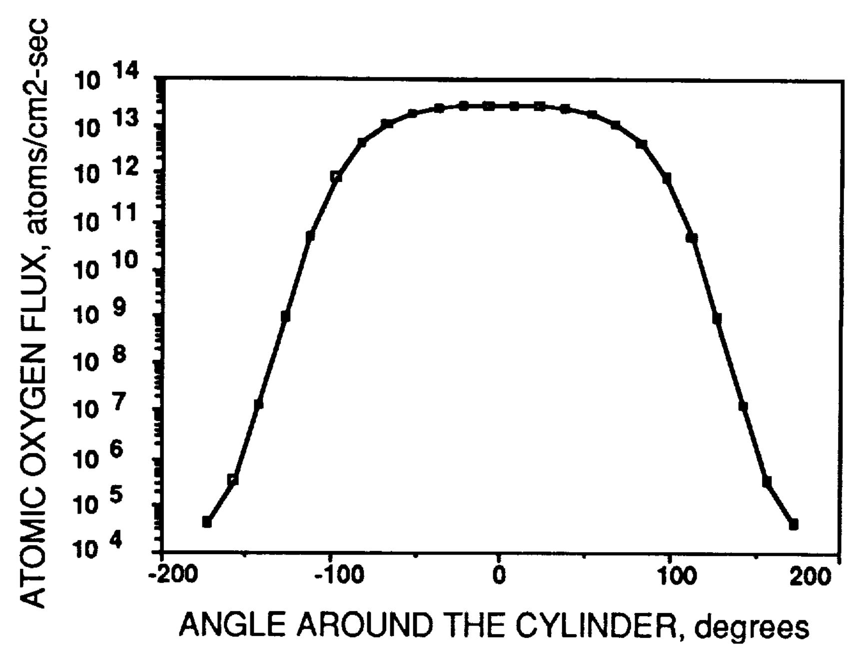

Figure 5. Variation of atomic oxygen flux around the cylindrical surface.

LDEF ATOMIC OXYGEN FLUENCE UPDATE,
AO EFFECTS ON COPPER GROUNDING STRAPS

Figure 6 shows the grounding strap for experiment Tray C-05 (Reference 3). The strap connects the tray thermal control blanket to a clamp fastened to the longeron between experiment Rows 5 and 6. The surface of the clamp is 113.1 degrees from the incident ram vector. At the edge of the clamp, the strap is bent down against the tray frame. The surface of the tray frame is 128.1 degrees from the ram vector. The photo shows some imperfection in fit-up between the strap and the frame and between the strap and the clamp. The strap was not originally intended as a test material. However, the arrangement does provide two surfaces that were exposed to the space environment for 6 years at angle to the incident ram vector that are known approximately.

Twelve such grounding straps are available from LDEF covering a wide range of incident angles for both leading and trailing surfaces. The surface properties of these straps are of interest. They provide data on the response of copper exposed in low earth orbit to varying levels of atomic oxygen and ultraviolet radiation . Also, examination of the strap surfaces provides a check on calculated exposures supplementing similar verifications of exposure based on tests of other materials.

Several surface properties of the copper grounding straps can be readily determined; solar absorptance, thermal emittance, and ESCA measurements of chemical composition. Also, reflected light from first and second surfaces of thin oxide coatings causes variations in reflectance. Methods of determining film thickness by way of optical interference effects are being examined. Thus far, data are available from solar absorptance and thermal emittance measurements.

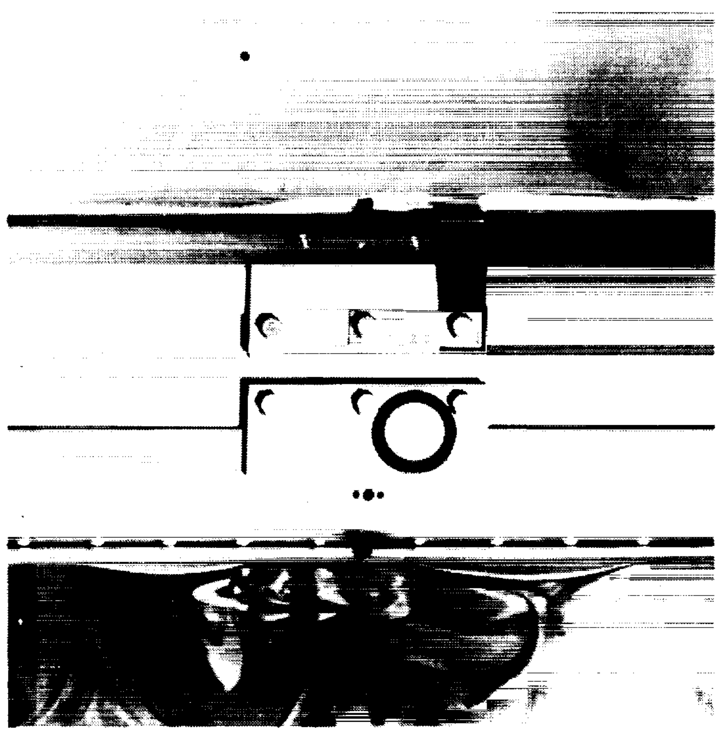

Figure 6. Grounding strap for the thermal control blanket of LDEF Tray C-05.

Possible factors causing absorptance and emittance to change are atomic oxygen exposure, solar exposure, and contamination. For copper grounding straps on leading surfaces of LDEF, contamination is not considered to be a factor. The surfaces were cleaned by atomic oxygen. On leading surfaces, the effects of the other two factors cannot be separated mathematically because they varied together. Both atomic oxygen exposure and solar exposure decreased with increasing incident angle. Atomic oxygen exposure decreased from 7.78E20 atoms/cm2 at Tray A-10 to 7.71E16 atoms/cm2 at Tray B-07. Solar exposure decreased from 10,700 to 7,100 equivalent sun hours for these experiments.

The variation in atomic oxygen exposure is greater than that for solar exposure and was chosen as the only independent variable for Figure 7. The data for apbsorptance and emittance at zero atomic oxygen fluence were taken on unexposed control material stored on earth during the LDEF flight. Figure 7 shows that solar absorptance is significantly increased by exposure in space. When solar absorbance is plotted against atomic oxygen fluence, the resulting function accounts for 88 percent of the deviation in sample values, although some of this effect may be caused by co-variation of solar exposure with atomic oxygen exposure.

No significant trend was found in the thermal emittance of copper grounding straps as a function of exposure on leading LDEF surfaces.

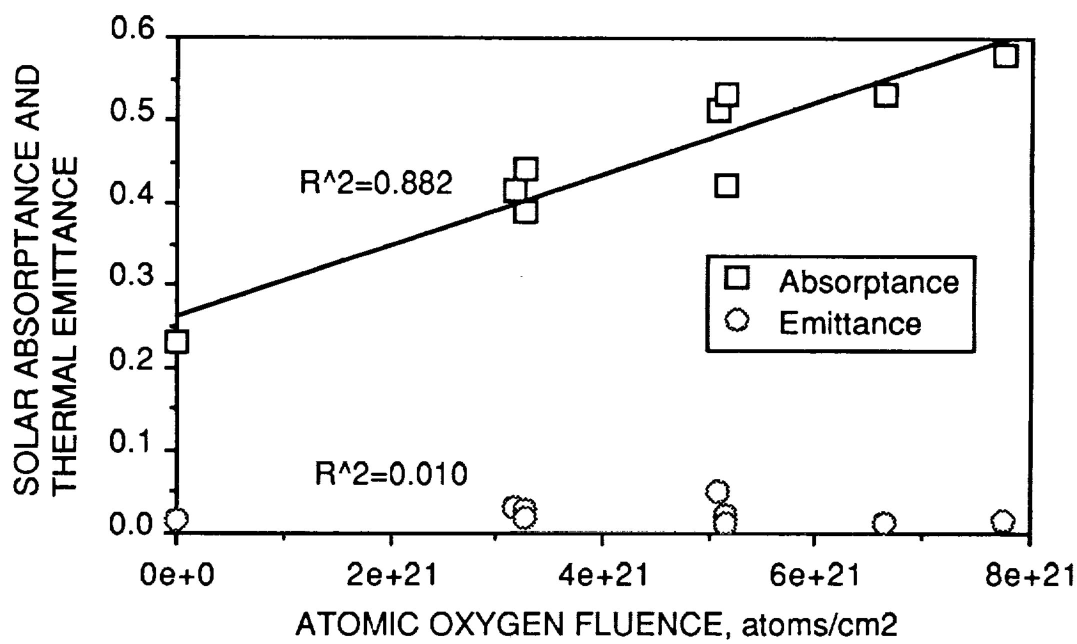

Figure 7. Absorptance and emittance of copper grounding straps on leading surfaces vs atomic oxygen exposure.

LDEF ATOMIC OXYGEN FLUENCE UPDATE, AO EFFECTS ON COPPER GROUNDING STRAPS

On trailing surfaces of LDEF the atomic oxygen exposure was near zero. The most likely variables affecting absorptance and emittance are contamination and solar exposure. Figure 8 shows solar absorptance and thermal emittance measurements on copper grounding straps from trailing experiments on LDEF plotted as functions of solar exposure in equivalent sun hours. The data given for zero hours exposure were taken from unexposed control material stored on earth during the LDEF flight.

Figure 8 shows a moderate dependence of solar absorbance on solar exposure. However, solar absorptance measurements for the exposed samples cluster about an average and do not show a consistent increase with increasing solar exposure. Most of the deviation in plotted values results from differences between the control sample and the exposed samples. The trend may be caused by contamination. If this is true then absorptance of the strap surfaces could be independent of solar exposure.

No significant difference in thermal emittance was noted between the control sample and samples exposed on LDEF's trailing experiments.

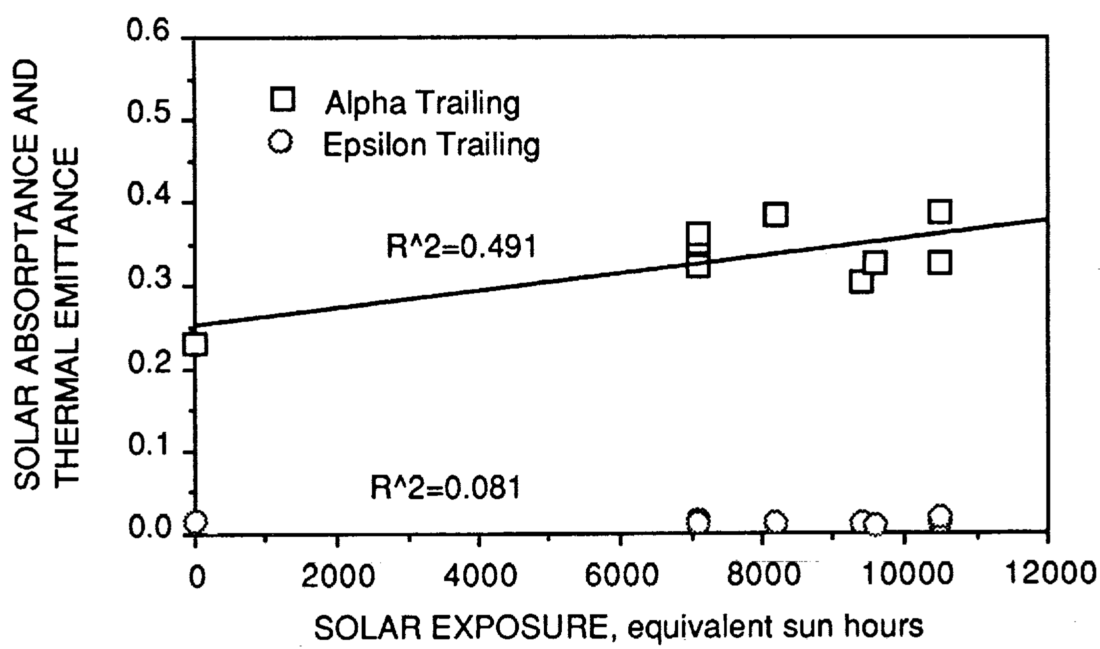

Figure 8. Absorptance and emittance of copper grounding straps on trailing experiments vs solar exposure.

REFERENCES

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3. Photo Number: KSC-390C-1110.06, LDEF Survey, SAEF II, Kennedy Space Center, Florida, February 1990.