INERTIAL UPPER STAGE SURFACE PROPERTY STUDY

Kira Jorgensen-Abercromby[1], Michael Guyote[2], and Jennifer Okada[2]

[1]*ESC Group/Jacobs Sverdrup, PO Box 58447, Mail Code JE104, Houston, TX, 77258-8447, USA,*
Email: kira.abercromby1@jsc.nasa.gov
[2]*Boeing LTS, Inc.*

1. INTRODUCTION

The Orbital Debris Program office at NASA Johnson Space Center (JSC) began a project four years ago termed NASS (NASA AMOS (Air Force Maui Optical and Supercomputing) Spectral Study) in an effort to determine the material type of orbiting objects using the slope and absorption features of reflectance spectra. The material type of these objects is important because *a priori* information on composition leads to better approximation of the density and thereby the mass and then the size of the object. Size estimates are necessary for the modeling of the debris environment. From our initial observations, the remote measurements increased in reflectance as the wavelength increased, a phenomenon that astronomers termed “reddening”. Most objects showed the reddening, but one in particular, the United States Inertial Upper Stage (IUS), did not show the effect (Jorgensen, et al. 2003). The reddening seems to dissipate after 1.5 microns (Jorgensen, et al. 2004). Laboratory measurements of the outer surfaces of a non-launched IUS were taken so that comparisons of similar materials could be made the materials viewed remotely.

The IUS was a two-stage booster used in conjunction with either the Shuttle or the Titan rockets to boost satellites into GEO or planetary orbits. The basic configuration of an IUS begins with the nozzle for the solid rocket motor and then the solid rocket motor is attached to the interstage structure. This interstage structure is capped by the second stage which includes the vehicle avionics and another, smaller, solid rocket motor. This stage is attached to the spacecraft. A picture of the rocket body is shown in Fig. 1.

The interstage is covered mainly in white paint while the stage 1 solid-fuel rocket motor is covered by multi-layer insulation (MLI). MLI has a very distinct absorption feature due to the copper color outer surface found near 5000 angstroms. The white paint has a strong feature near 3900 angstroms. MLI consists of five layers of aluminized Kapton and Dacron net spacers. The surface under the MLI on the rocket motor casing is black conductive paint. The nozzle consists of an outer surface of a carbon/carbon matrix which is covered with MLI prior to launch. A model using the four materials mentioned was created that predicts the spectral response of the IUS remote measurements. Five IUS rocket bodies were observed and these spectra were compared to the predictions from the models. The IUS remote measurements, in addition to having little to no reddening, did not show the absorption feature due to MLI. The feature is very prominent and due to the amount of MLI on the surface, it should be visible at most orientations.

Figure 1: Picture of an IUS with both stages in the space shuttle bay (courtesy of NASA)

2. RESULTS

The laboratory measurements were taken with an Analytical Spectral Device (ASD) field spectrometer with a resolving power of 10 nanometers at 2 microns. Multiple measurements for each material are obtained to ensure repeatability. All remote observations were taken using the 1.6 meter telescope and the spectrometer named Spica., which is an Acton SP-500i spectrometer with three selectable gratings although for this project the red and blue filters are used exclusively. The center wavelengths are 4500 angstroms for blue grating and 7500 angstroms for red grating. For calibration of the spectrometer, a mercury lamp is used for the blue wavelengths and a neon lamp is used for the red (Nishimoto, et al. 2001). For this paper, only the data taken using the blue grating will be used.

The remote measurements of the five IUS rocket bodies were taken on three different nights using the Air Force Maui Optical and Supercomputing (AMOS) site 1.6 meter telescope. All five observations have similar shape and slope which increases drastically shortward of 4000 angstroms and flattening out through 6000 angstroms. These observations, as is the case for the model shown above, are scaled to one at 6000 angstroms. When comparing the spectrum taken remotely with those taken in the laboratory, it is important to take orientation of the object into consideration. Spent rocket bodies, however, are not in a controlled attitude and therefore can be in virtually any orientation. In an effort to establish the possible change in the reflectance spectrum for an object based

Proceedings of the Fourth European Conference on Space Debris, Darmstadt, Germany, 18-20 April 2005
(ESA SP-587, August 2005)

on orientation, a model was created that steps through the possible orientation modes adding and subtracting material as it comes into and out of view of the observer. In general, two models will be discussed. Model 1 is based on the pristine materials while model 2 incorporates materials that have already flown in space and thus have some space weathering effects integrated. The white paint in model 2 seems to match the curvature of the remote measurements better than the pristine materials in model 1.

Fig. 2 shows five orientation changes for the remote measurements assuming MLI is not covering the nozzle. The top left of the figures depicts the spectrum for the orientation of the longest dimension (length) facing the observer. As one moves toward the nozzle of the rocket body, more MLI comes into view, which in the figures that move to right. Because no white paint is used when just the nozzle is in view, there is only one model since model 1 and 2 in this case are the same. The bottom row of Fig. 2 shows the configuration as the rocket body moves toward the stage end of the object. As one can see, the best match for orientation is the final figure which is when the object has the stage end facing the observer. Cartoons of the orientation are shown on each image.

The absorption feature due to MLI seen in the models near 5300 angstroms is not visible in the remote measurements and a few possibilities arise for the cause. The first is that the orientation of the rocket body is such that no MLI is shown to the observer. In this case, only white paint would be visible as seen in the last figure of Fig. 2. This possibility will be valid until orientation information can be determined and at this time the authors have no knowledge on the orientation. A second possibility is that glints or specular reflections from MLI change the spectral reflection. All of the laboratory observations are taken at diffuse angles and therefore at specular angles one could get a different looking spectrum. A project being conducted currently

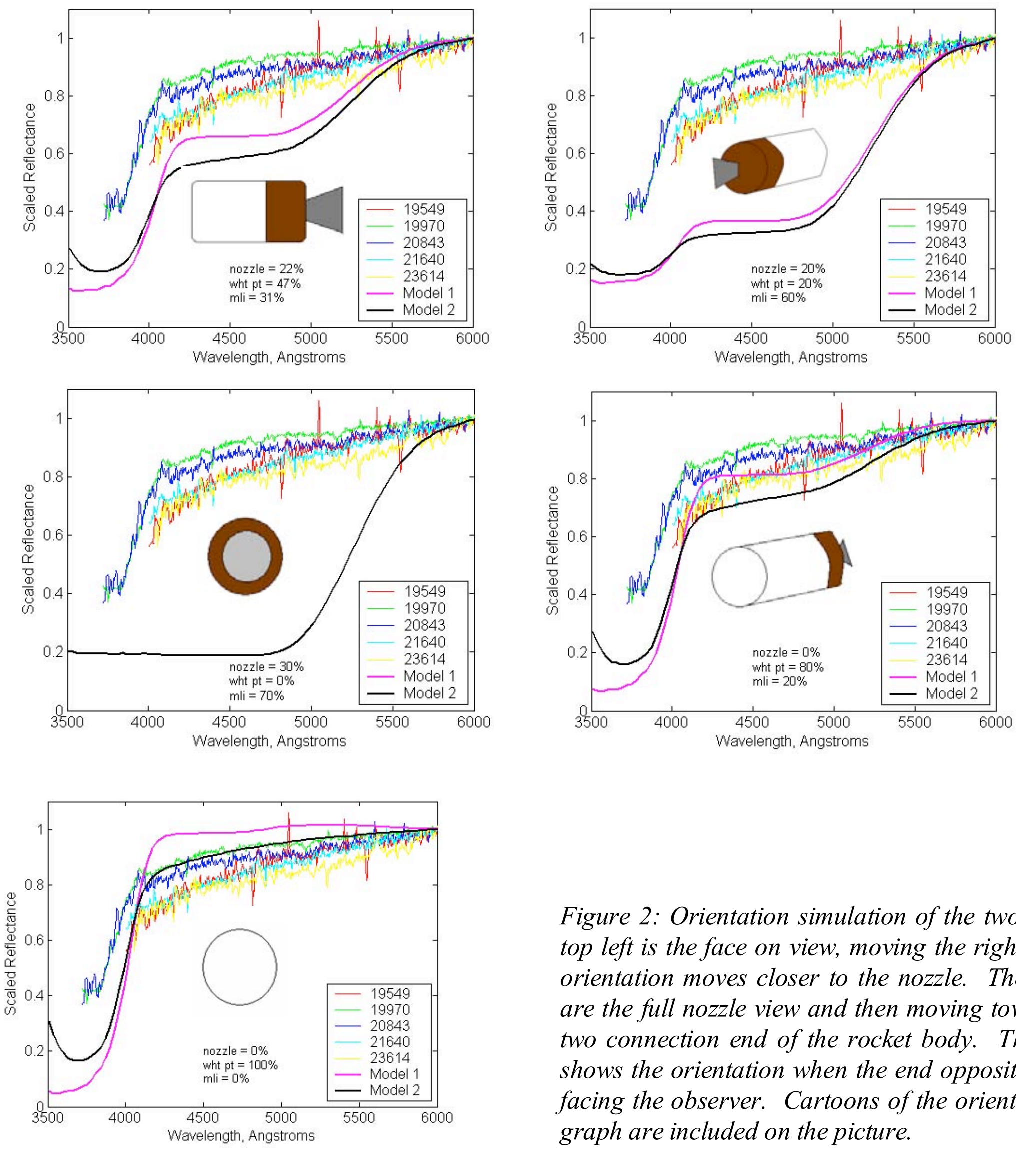

Figure 2: Orientation simulation of the two models. The top left is the face on view, moving the right shows as the orientation moves closer to the nozzle. The middle rows are the full nozzle view and then moving toward the stage two connection end of the rocket body. The final figure shows the orientation when the end opposite the nozzle is facing the observer. Cartoons of the orientation for each graph are included on the picture.

shows that for Kapton (the outer surface of MLI) an increase in overall reflectance is seen when the object has specular glints but the shape and features remain similar (Private Communications, 2005). This may not be the case for other materials or for this exact kind of MLI so the authors will examine other solutions for the lack of the MLI feature and assume that the specular glints are not the cause. A third possibility is that the space environment is damaging and thus changing the surface properties of the MLI. If that is the case, a different spectrum would be observed and could explain the missing MLI absorption feature. A final possibility is that the MLI is missing completely.

MLI is covering the nozzle when the IUS leaves the launch pad. Since the remote measurements show no MLI it is necessary to see if the MLI has come off the nozzle or is no longer producing the same spectrum. Fig. 3 depicts two models and the same five remote measurements. The left figure shows the result of MLI being present on both the nozzle and the solid rocket motor and the right figure depicts the result of MLI being present only on the nozzle. One can tell that the spectra do not match and the MLI is not visible. Whether it is orientation, specular components, damage to the MLI, or that the MLI is completely missing, is still unknown at this time. Imaging the IUS would help solve the problem of orientation and specular information would help with the glint possibility, neither of which were able at the time of this paper.
To test the hypothesis of MLI covering the solid rocket motor coming off and thus showing the underlying surface of black conductive paint, models were created that stepped through the change in MLI amounts. Model 1 uses pristine material measured in Florida and model 2 uses flown white paint. An assumption was made for these models that no MLI is covering the nozzle and so the material used for the nozzle was carbon. Fig. 4 shows two models compared with remote measurements of the five IUS rocket bodies. These six figures show the progression of loosing MLI and exposing the underlying surface of black conducting paint. The figure on the top left starts with no MLI and then each figure adds five percent MLI back into the model with the last figure showing all MLI and no black paint. The remote spectra match best with the two top figures rather than the two bottom figures due to the lack of the MLI feature seen near 5000 angstroms. From this analysis, no concrete reason as to why the MLI is missing can be determined. If one disregards orientation and spectacular glints, it is possible that, instead of missing, the MLI is no longer looking pristine and showing laboratory like absorption features.

3. CONCLUSIONS

Due to the lack of information regarding orientation, it is difficult to make a resounding conclusion regarding the missing MLI feature in the spectrum. By examining the orientation only, it would appear that the objects are all facing the observer in the same orientation regardless of its point in its orbit. This orientation would be with the stage 2 attachment end (stage _ interface plane in the direction of the observer) facing the observer as seen in the final picture of Fig. 4. Holding orientation stable with the nozzle facing the observer showed that the MLI is not in the remote spectra. It could have been destroyed during the burning of the first stage. Holding the orientation stable in the face-on configuration yields the result that the MLI is either missing or no longer has the reflectance properties seen in the laboratory. If orientation can be determined, the next step of this project is to determine the true effect of the specular glint. If the initial findings of the current study prove to be true and the object's spectrum does not change shape, the next step would be to determine the properties of MLI that has been damaged by the space environment. The problem of the missing MLI feature stills lives on but, directions to take to solving the problem are clearer and more distinct.

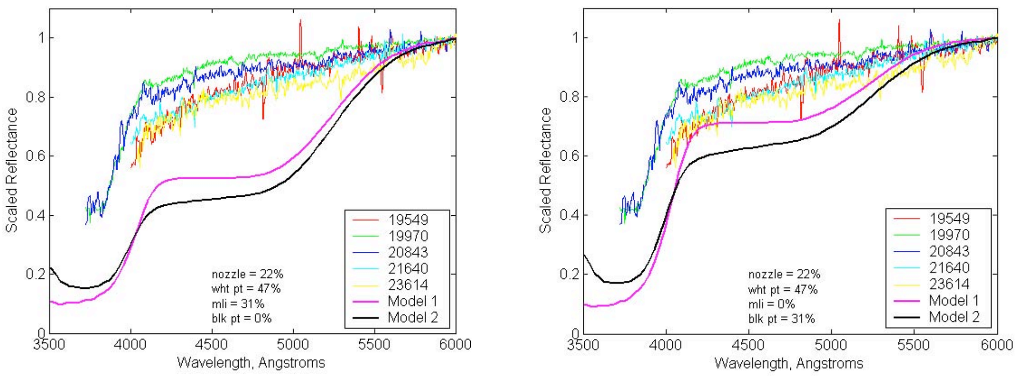

Figure 3: Models of MLI presence on the nozzle of the IUS. Model 1 uses pristine material and model 2 uses flown white paint. The figure on the left shows what the spectrum would look like if the MLI was still on the nozzle and covering the solid rocket motor. The figure on the right depicts the spectrum if the MLI on the solid rocket motor was not visible (or no longer there) but still remained on the nozzle. No evidence of the MLI is seen in the remote samples.

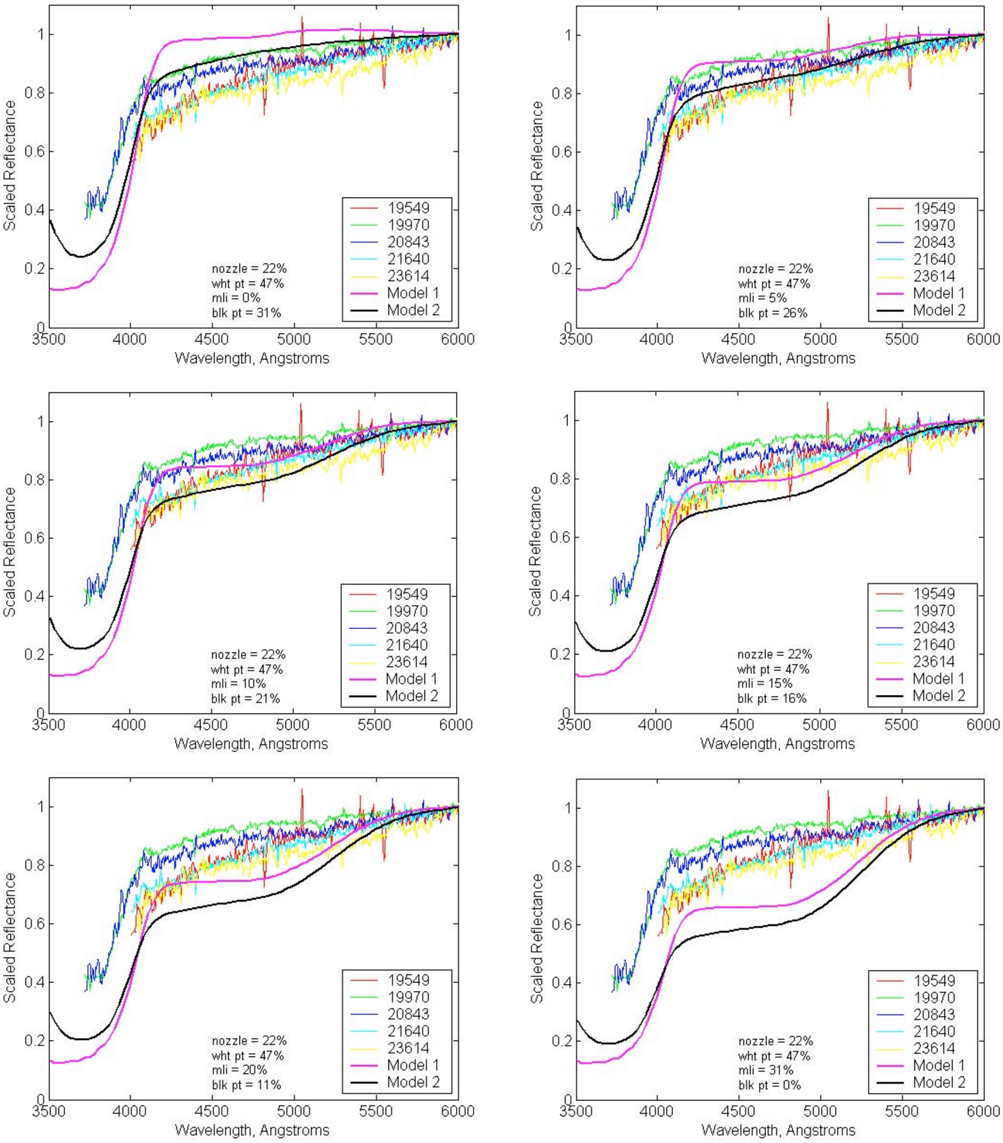

Figure 4: Models of spectrum compared with remote spectrum. Model 1 uses pristine material and model 2 uses flown white paint. These six figures show the progress through loosing MLI and showing the underlying surface of black conducting paint. The figure on the top left starts with no MLI and then each figure adds five percent MLI back into the model with the last figure showing all MLI and no black paint. The remote spectra match best with the two top figures rather than the two bottom figures due to the lack of the MLI feature seen near 5000 angstroms.

4. ACKNOWLEDGEMENTS

The authors would like to thank Peter Maricich of Boeing for helping us get to Florida to take the measurements and keep us clear on the IUS in general. Also, the authors would like to thank those who took the telescope data at AMOS (Dennis Liang and Kris Hamada), those in the optical office at NASA JSC (Tracy Parr-Thumm, Kandy Jarvis, Edwin Barker, and Eugene Stansbery), those helping with the specular measurements (Maile Giffin and Kris Hamada) and those in the Boeing offices (John Africano and Doyle Hall) for their help and guidance.

5. REFERENCES

Jorgensen, K., et al., Obtaining Material Type of Orbiting Objects through Reflectance Spectroscopy Measurements, *2003 AMOS Technical Conference*, Wailea, Maui, Hawaii, 8 – 12 Sep 2003.

Jorgensen, K., et al., Observations of J002E3: Possible Discovery of an Apollo Rocket Body, Presented at *The Division of Planetary Sciences*, Monterey, CA Oct 2004.

Nishimoto, D.L., Africano, J.L., Sydney, P.F., Hamada, K.M., Kervin, P.W., SooHoo, V., Stansbery, E.G., Spectroscopic observations of Space Objects and Phenomena using Spica and Kala at AMOS, *Proceedings of SPIE*, Vol. 4490B, San Diego, California, 29 Jul - 3 Aug 2001.

Private communications (M. Giffin, Oceanit), Jan 2005.