ANALYSIS OF DEBRISAT DATA COLLECTION AND PROCEDURES

Elizabeth Campa
University of Florida
Rafael Carrasquilla
University of Florida
Norman Fitz-Coy
University of Florida

1. Abstract

As a joint effort between the NASA Orbital Debris Program Office (ODPO), the Department of Defense (DoD), The Aerospace Corporation, and the University of Florida, the DebriSat project was created to simulate and study the results of an on-orbit collision of modern low earth orbit (LEO) satellites. A hypervelocity impact test was performed in Tennessee on a representative LEO mock-up. The post-HVI test remains of the test article and surrounding soft-catch arena panels were collected and shipped to the University of Florida for characterization. The resulting data will be used to update previous orbital debris engineering models for the purposes of increasing space situational awareness in the hopes of guiding future space-related policies and improving preparation for future incidents involving space debris. This paper provides a general overview of data collection methods, status of debris characterization efforts, changes in debris processing priorities, and procedural modifications aimed at increasing processing efficiency by student technicians. Furthermore, due to the pandemic caused by COVID-19, the significance of having updated procedures outlining current priorities has changed.

2. Background

In order to update past orbital debris engineering models used by NASA Orbital Debris Program Office (ODPO) and the Department of Defense (DoD), the DebriSat Project was created with the plan of representing a modern Low Earth Orbiting (LEO) satellite in 2014 [1]. This test article was then shipped to Tennessee where a hypervelocity impact (HVI) test was performed. Prior to the HVI, the interior of the test chamber surrounded with panels of foam to form a soft-catch area in order to minimize the effects of the chamber walls on the debris. Post the HVI test, the remaining materials inside the chamber were collected and sent to the University of Florida (UF) for further processing. The goal was to collect, process, measure, and archive debris fragments.

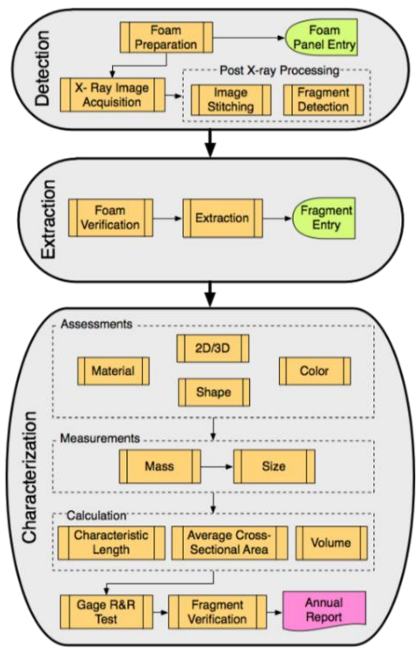


Figure 1. Post HVI Activities

The UF-obtained debris characterization data includes metrics such as material, shape, size, mass, characteristic length (LC), area-to-mass ratio (AMR), and average cross-sectional area (ACSA) for each debris fragment. In addition to the characterization data, UF technicians use several imaging systems to facilitate (i) facilitate extraction of debris embedded within the soft-catch area panels, (ii) provide images of individual debris fragments, (iii) measurement acquisition, and (iv) provide 3D models known as space carvings of debris for larger fragments. Furthermore, due to the pandemic caused by COVID-19 and the resulting shutdowns, there has been a shift in priorities involving emphasis on fragments greater than 10 mm. Prior to the pandemic, technicians were processing fragments ranging from 2-10 mm and those greater than 10 mm. Currently, fragments in the 2-10 mm range are counted for later processing and those greater than 10 mm are fully processed. During the project, procedures have been altered to increase efficiency and accuracy of results. Said steps include detection, extraction, and characterization, each with their own sub-tasks (Fig. 1). This paper will outline the major updates to the procedures.

3. Post processing

3.1. Detection

Copyright © 2022 Advanced Maui Optical and Space Surveillance Technologies Conference (AMOS) – www.amostech.com

The first step in post processing is fragment detection. In this stage, technicians must prepare the foam panels for processing and it is then X-rayed to use resulting images to detect the embedded fragments.

As of Fall 2021, a Smiths Hi-Scan Detector was acquired by NASA and implemented due to failures from the prior system. Previously, a North Star Imagine (NSI) X-ray Computed Topography (CT) unit was used to detect fragments. The NSI machine process took approximately 20 minutes for X-ray imaging and was not operational from Fall 2018 to Fall 2020. After remaining inoperative for an extended period of time, the Smiths machine was acquired. A 2-position shelf support system (Fig. 2) was developed and implemented in which panels are loaded onto the system and run through the Smiths detector to obtain 12 images. The shelf system, referred to as the “shoe” (Fig. 3) consists of two sets of inserts, attached to the leading and trailing edges of the shoe, which can be configured to provide two different angles to image the inserted panel.

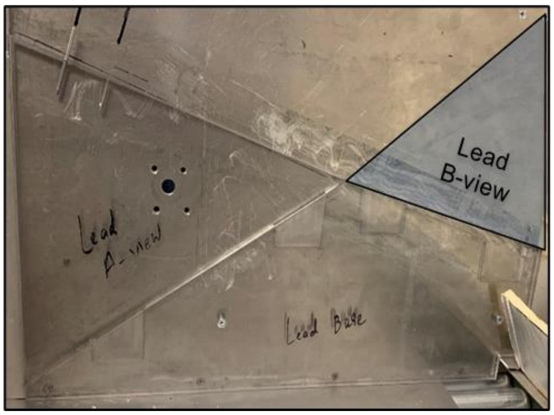


Figure 2. Shelf supports with simulated B-view insert

Figure 3. Hi-Scan 6046si X-ray scanner with added rollers and shoe.

Technicians align the shelves accordingly using metal pins to ensure the panels remain fixed during imaging. A hooked dowel is then used to hook into an aluminum eyelet to facilitate lowering the foam panel and the shelf into the unit (Fig 4). Machined-key image indexers are then placed on the shoe for an alignment reference. Once the images have been collected, an updated panel map (Fig. 5) output with filtering capabilities is generated. Fragments are assigned a fragment ID that is used by technicians in the extraction process to label the ID as a true positive, false positive, or false negative which allows for refinement in the detection software.

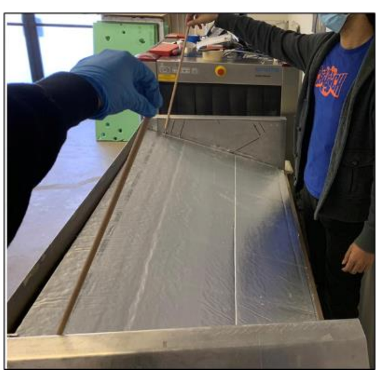


Figure 4. Technicians demonstrating hook system operation

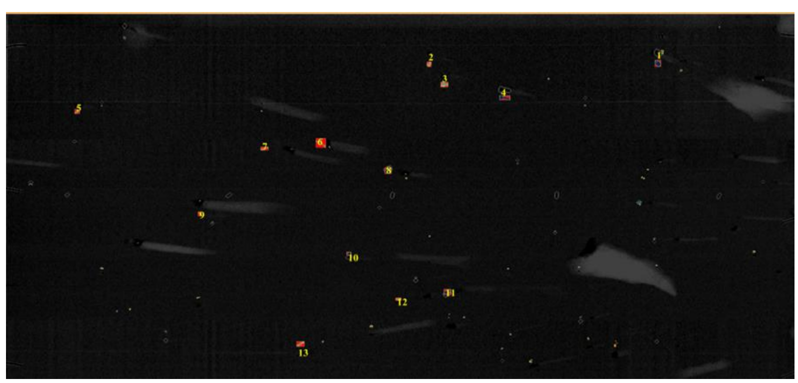


Figure 5. Rendering of a post-processed X-ray with extraction labeling

The total time for imaging and post imaging is approximately 70 minutes which varies on operator experience. New procedures have created a more reliable system with higher accuracy for fragment extraction. Currently, technicians are working on the completion of X-ray imaging of full panels, fractured panels, and DebrisLV panels.

Copyright © 2022 Advanced Maui Optical and Space Surveillance Technologies Conference (AMOS) – www.amostech.com

3.2. Extraction

Once panels have been X-ray imaged and post-processed, they are passed on to the extraction process. In this process, a selected panel is placed on a board and the post processed X-ray image with fragment ID's is projected onto the board for labeling. Technicians use color coded pins to map the fragment locations accordingly using red pins to mark fragments >10 mm. These panels are then carefully taken to the extraction table where technicians place a metal grid used for mapping in order to later identify where in the grid the fragment was placed. Depending on the density of the foam, tools are chosen accordingly to begin to carefully carve in an approximately 1" x 1" area around the identified fragment location. Once the fragment has been extracted, it is placed in an appropriate container and labeled accordingly. The technician then must return to the site and carve the foam the rest of the way through the foam to ensure there are no further fragments in the area that may have evaded detection due to the other fragment. While extraction is being performed, each fragment is logged appropriately, and extraction is complete once all marked fragments >10 mm have been removed. In order to ensure all fragments have been removed, technicians then look for scorching, pitting, or tunnels into the panel that do not go straight through the panel. excess dust that remains is reviewed for further fragments and labeled as panel dust. Currently, procedures outline that larger fragments (>10 mm) must be extracted and smaller fragments (2 mm – 10 mm) are counted using X-ray images. Fractured panels are defined as panels less than 2/3 of the original panel size. Loose and embedded fragments from these panels are collected and individually bagged, labeled, and stored for later characterization.

3.3. Characterization

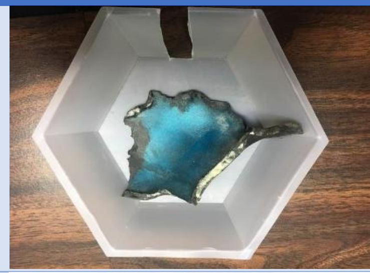
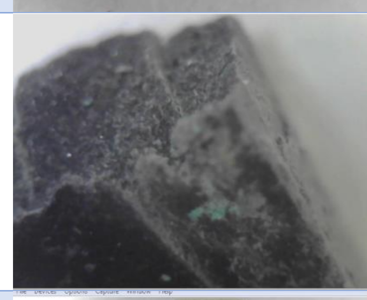
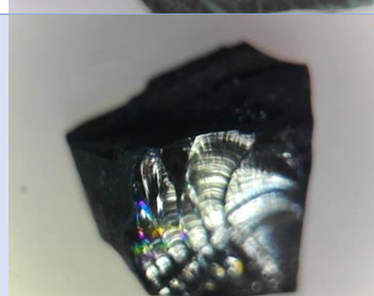
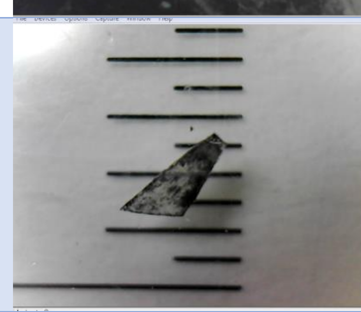
3.3.1 Assessments

Once fragments have been extracted and their location has been labeled, they progress to the characterization process. Here, fragments are assessed for material, shape, size, and color. After assessment, fragments are then massed and imaged and the resulting data is then used to generate the physical attributes of the fragment (i.e., mass, characteristic length, average cross-sectional area, volume, and density). The final step in the characterization process is the verification of each fragment to ensure the validity of the collected data collected (i.e., all the data is present and is consistent for the fragment).

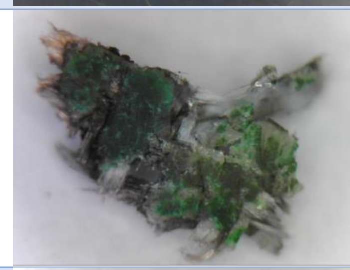
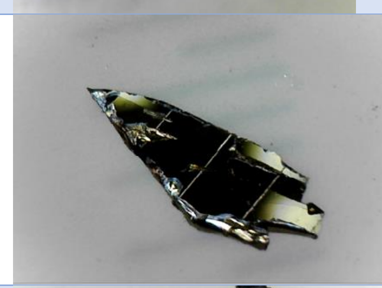
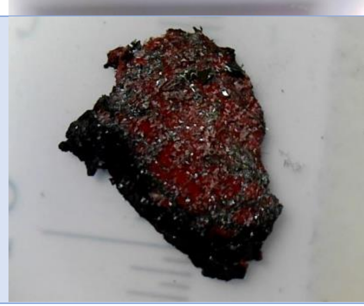
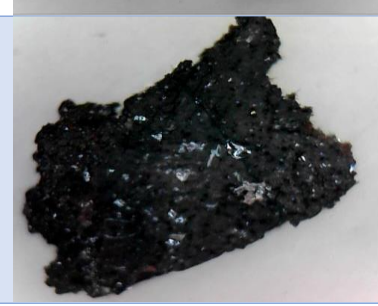
The assessment process is compiled of qualitative observations involving material, shape, size, and color. Technicians are currently prioritizing fragments >10 mm. The material choices outlined in Table 1 are as follows: aluminum (AL), carbon fiber reinforced polymer (CFRP), copper (CU), epoxy, glass, Kaplan tape (Kap), Kevlar (Kev), multi-layer insulation (MLI), printed circuit board (PCB), plastic, solar cell (SCELL), silicone (SIL), stainless steel (SS), and titanium (TI). Technicians in this stage are required to select metallic looking fragments as metal due to a lack of information identifying which type of metal it may be. However, this does not apply for copper fragments as they are almost always in the form of copper wires. This is later verified using the material's calculated density. Some fragments may be composed of multiple materials in which it is instructed that all materials be listed in the database. An example of this may be CFRP with epoxy or copper wire with plastic insulation (Fig. 6). Shapes include straight rod/needle/cylinder, bent rod/needle/cylinder, flat plate, bent plate, nugget/spheroid/parallelepiped, and flexible. Technicians are trained to select the correct material(s), shape, and color assessment for each fragment based on its characteristics. In order to accurately see small details like these, digital microscopes are used to display the camera feed on the technician's computer screen. Fragments are also classified on being either 2D or 3D based on the z-dimension (3D fragments have a minimum z-dimensional measurement of 3 mm while 2D fragments are under 3 mm). Table 2 displays the status of fragments assessed as of May 1, 2022.

Copyright © 2022 Advanced Maui Optical and Space Surveillance Technologies Conference (AMOS) – www.amostech.com

Table 1. Material names and sample images

Material Name	Material Sample image	
Metal		
CFRP		
CU		
Epoxy		
Glass		
Kap		

Copyright © 2022 Advanced Maui Optical and Space Surveillance Technologies Conference (AMOS) – www.amostech.com

Material Name	Material Sample image	
Kev		
MLI		
PCB		
Plastic		
SCEL		
SIL		

Copyright © 2022 Advanced Maui Optical and Space Surveillance Technologies Conference (AMOS) – www.amostech.com

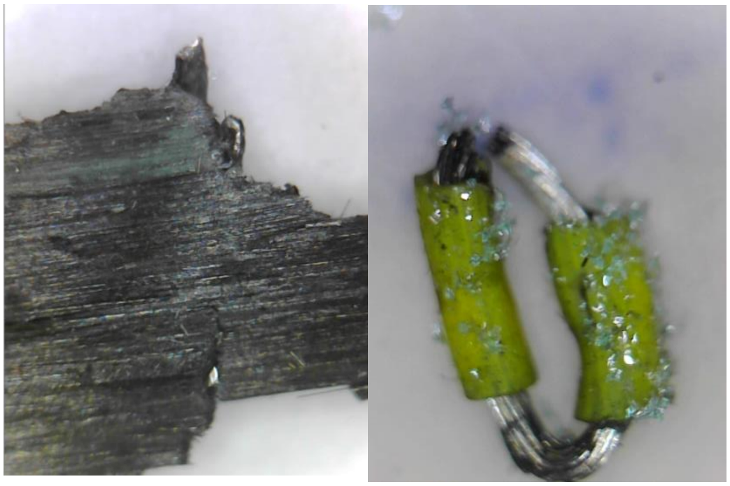


Figure 6. CFRP with epoxy and metal (left); copper wire with plastic insulation (right)

Table 2. Material Assessment status

Primary Material	Assessment Status		
	2D	3D	Total
AL	1,014	141	1,155
CFRP	59,269	408	59,677
CU	8,120	176	8,296
Epoxy	4,449	474	4,923
Glass	3,731	191	3,922
Kap	675	82	757
Kev	609	16	625
MLI	2,263	752	3,015
PCB	990	60	1,050
Plastic	4,464	222	4,686
SCEL	402	3	405
SIL	759	32	791
SS	446	86	532
TI	253	40	293
Metal*	4,585	1,611	6,196
Total	92,029	4,294	96,323

3.3.2. Measurements and Calculations

After assessment, fragments move to the measurement process where they are massed and imaged. The controlled mass measurement room is equipped with two workstations (WS). WS1 is equipped with a microbalance (5.0 g capability), medium balance (200.0 g capability), and a large balance (510.0 g capability). WS2 is equipped with a microbalance and an X-large balance (3100.0 g capability). Depending on the size of the material, a balance is selected, and the mass, humidity, and temperature are directly input into the database. Size is assessed with the use of either a 2D or 3D imager, based on whether the fragment itself is 2D or 3D. The 2D imager (Fig. 7) is comprised of a single camera, front and back lighting, and a 45° prism mirror which gives the capability of measuring all three orthogonal dimensions (X,Y,Z directions) [2]. The images are then processed through image-processing software (Fig. 8) where dimensional measurements are displayed. Densities can then be calculated using the combined volume and mass values which are then applied to later identify which of the possibly metal assignments the fragment falls into. The 3D imager (Fig. 9), used for 3D fragments, is made up of a 6-camera array system mounted on an arc above a rotating turntable the color of a green screen combined with a greenscreen background. The turntable is surrounded by three studio lights and a computer for image processing. A fragment is placed onto the center of the turntable and each of the six cameras capture an image. The table then turns 18º and another set of images is acquired. This continues until the table has rotated a full 360º. These images are then processed through an image processing software which creates a 3D digital model of the fragment known as a space carving. The technician must validate the model and confirm the space carving looks like the fragment itself. At times, due to the fragment being too specular or other issues, the space carving may not have captured the full fragment. If the fragment passes, it is confirmed and added to the database server.

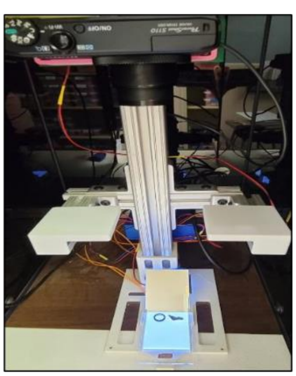


Figure 7. 2D imaging system

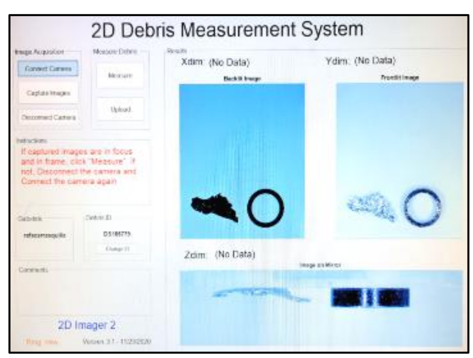


Figure 8. 2D Debris Measurement software

Copyright © 2022 Advanced Maui Optical and Space Surveillance Technologies Conference (AMOS) – www.amostech.com

Figure 3. 3D imaging system and post processed image

3.3.3. Gage R&R Test and Fragment Verification

After calculations have been completed, Gage Repeatability and Reproducibility (Gage R&R) tests completed to quantify measurement system variation and the sources. After every 1,000 characterized 2D fragments and every 500 characterized 3D fragments, five randomly selected fragments are tested by three experienced level 3 technicians. The technicians test each fragment by running them through the characterization process once more. The last step before submitting the data collected for final review is for level 3 technicians to verify all the characterization data. Metal assessment is resolved using density calculations and operators review all images taken of the fragment to ensure it was fully captured. If the fragment was not captured correctly in imaging, it is marked as failed and sent back to imaging. If it fails for assessment, the technician must make corrections to the database and another technician must complete final verification. This process takes an average of 8.5 minutes per fragment.

4. Conclusion

Ultimately, the current procedures surrounding HVI post processing allow for more accurate and efficient results in comparison to prior practices. Although some processes, such as X-ray takes longer than it used to, improved outcomes are found. Technicians and others constantly suggest improvements for the project and these are implemented and tested whenever possible. For example, a process in which fragment extraction would be completed using a 2” x 2” square punch tool was tested, and it was determined to be ineffective due to its inability to penetrate medium-density panels. However, some of these improvements are constantly applied, such as changes to the 3D imager’s software. Changes are made to make increase the speed of the post imaging process along with the actual imaging time itself. This has caused a reduction of 70% for imaging processing times. The overall project is expected to be completed in the near future and with further changes, that time may be closer than expected, while still upholding high standards to ensure the best results possible.

5. Acknowledgements

We thank NASA, the DoD, Jacobs, and The Aerospace Corporation for their continued support of the project without whom this work would not have been possible. We would also like to extend a thank you to our colleagues and the work they have put into project.

Copyright © 2022 Advanced Maui Optical and Space Surveillance Technologies Conference (AMOS) – www.amostech.com

References

[1] M. A. Rivero, "DebriSat: Fabrication of a Representative LEO Satellite," University of Florida, Gainesville, 2018

[2] S. Allen, B. Symoens, V. Reali and e.al, "Characterizing DebriSat Fragments – Preliminary Results," in 69th International Astronautical Congress, Bremen, Germany, 2018

Copyright © 2022 Advanced Maui Optical and Space Surveillance Technologies Conference (AMOS) – www.amostech.com