# A Comparison of the SOCIT and DebriSat Experiments

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## ABSTRACT

This paper explores the differences between, and shares the lessons learned from, two hypervelocity impact experiments critical to the update of Department of Defense (DOD) and National Aeronautics and Space Administration (NASA) satellite breakup models. The procedures as well as the processes of the fourth Satellite Orbital Debris Characterization Impact Test (SOCIT4) were analyzed and related to the ongoing DebriSat experiment. SOCIT4 accounted for about 90% of the entire satellite mass, but only analyzed approximately 59% with a total of approximately 4,700 fragments. DebriSat aims to recover and analyze 90% of the initial mass and to do so, fragments with at least a longest dimension of 2 mm are collected and processed. DebriSat's use of modern materials, especially carbon fiber, significantly increases the fragment count and to date, there are over 126,000 fragments collected. Challenges, such as procedures and human inputs, encountered throughout the DebriSat experiment are also shared. While, SOCIT4 laid the foundation for the majority of DebriSat processes, the technological advancements since SOCIT4 allow for more accurate, rigorous, and in-depth, procedures that will aid the update of satellite breakup models.

## 1 INTRODUCTION

The U.S. Space Surveillance Network (SSN) is capable of identifying orbiting objects down to approximately 10 cm in diameter in Low Earth Orbit (LEO), and approximately 1 m in diameter in the geosynchronous region [1,2]. However, objects smaller than 10 cm are not actively tracked by the SSN in LEO. The satellite breakup models are used to better understand the impact of the fragments that is not actively tracked, as well as supplement current data on tracked objects. To simulate on-orbit satellite collisions in LEO, hypervelocity impact tests are conducted on the ground. Impact test results from the Satellite Orbital Debris Characterization Impact Test (SOCIT) series and DebriSat, are used to develop and improve the breakup model [1]. Tests conducted before SOCIT focused mostly on the lethality of the breakup and had low testing fidelity test articles.

The SOCIT tests were a series of hypervelocity impact tests with test dates spanning from December 1991 to January 1992. The fourth test, SOCIT4, targets a flight ready Navy Transit satellite bus. SOCIT4's goal, was to account for 90% of the total mass of the satellite, but only analyzed about 59%. Most of the results from the SOCIT4 test are used in the current breakup models. The SOCIT series occurred at the Arnold Engineering Development Center Range G, and data analysis was conducted by the General Research Corporation (GRC) and Kaman Sciences.

DebriSat's goal, much like that of SOCIT4, is to update the breakup model for modern LEO satellite collisions and account and analyze 90% of the satellite's total mass. There are three phases of the DebriSat project: the design and fabrication of DebriSat test article, the impact test, and the post-impact process consisting of the collection of satellite fragments equal to or larger than 2 mm. DebriSat is a joint project involving the NASA Orbital Debris Program Office, the Air Force's Space and Missile System Center, the Aerospace Corporation, and the University of Florida (UF). DebriSat's hypervelocity impact test was conducted at the same test facility as SOCIT4 [2].

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The DebriSat experiment builds upon the previous impact tests, utilizing more modern materials representative of LEO satellites today. This paper studies the design, tests, and post-impact processes of SOCIT4 and DebriSat.

## 2 HYPERVELOCITY IMPACT TEST

### 2.1 Satellite Design

One of the most significant differences between the two tests is the design of the satellites. The SOCIT4 experiment utilized a readily available satellite -- a US Navy Transit satellite constructed in the 1960's -- for its hypervelocity test [1]. Transit-O 22 (also known as Oscar 22) was a flight-ready satellite selected for the hypervelocity test and followed the typical Oscar design [1].

SOCIT4's Oscar satellite was made up of an octagonal core with a 46 cm diameter and a height of about 25 cm [1]. It was composed primarily of materials such as aluminum, copper, fiberglass, plastic, and steel [3]. Although the original Oscar satellites also included flight-ready spacecraft batteries and solar panels, these components were removed for the SOCIT4 impact test [4]. The batteries were replaced with representative aluminum blocks to prevent the need for a toxic clean-up after testing. The solar panels were removed because they were one of the earlier targets for a previous SOCIT test. The test-ready Oscar weighed 35 kg [1,5]. However, while Transit-O 22 was an accurate representation of the Transit designs and that of other typical satellites constructed throughout the 1960's, it no longer reflects today's satellite compositions.

To ameliorate the discrepancy between the SOCIT series and modern satellites, DebriSat was created with the intention of broadening the scope of satellites represented by the DOD and NASA Standard Satellite Breakup Model-- in particular, modern LEO satellites [2]. The UF, with the assistance of the Aerospace Corporation, conducted an in-depth survey of 50 modern LEO satellite missions and from the results, selected components based on a specific set of criteria [1,2]. These criteria included components that were most popular in current satellites, had the potential to be extremely common in the future, or were new standards introduced post-1992 [1]. Much of the flight hardware such as the flight computer, circuitry, battery, and propulsion system were emulated to reduce equipment costs [1]. Aerospace subject matter experts for each subsystem were consulted to ensure that emulated components were representative of actual spacecraft components. Distinctions between the SOCIT4 and DebriSat satellite designs are shown in Tab. 1.

*Table 1. Key Distinctions of SOCIT4 and DebriSat Satellite Designs [1,5]*

| Characteristics | SOCIT4 | DebriSat |
|---|---|---|
| Propulsion System | No | Yes |
| Attitude Control | Magnetic Hysteresis Rods | Reaction Wheels and Magnetorquers |
| External Heat Protection | Aluminized Mylar | Multi-layer Insulation (MLI) |
| Composite Materials | No | Yes |
| Emulated Components | Solar Cell Batteries | Majority of components |

DebriSat was constructed to be a 50 kg class satellite but included components from a broad range of satellite mass classes [1]. This enables DebriSat to be representative of different satellite platforms and not just 50 kg class satellites. The body was a hexagonal prism with a diameter of 60 cm and a height of 50 cm. DebriSat utilized modern components such as coverglass interconnected cells (CIC) solar cells, multi-layered insulation (MLI), and carbon fiber reinforced polymer (CFRP). The CIC solar cells are routinely used in LEO satellite designs because of their high power generating efficiency, MLI is commonly used in applications requiring high performance thermal insulation, and CFRP materials are used for their high material strength to low mass and thermal insensitivity. The common materials used in the construction of DebriSat were CFRP, aluminum (Al), and stainless steel.

### 2.2 Hypervelocity Tests

Both SOCIT4 and DebriSat satellites were impacted by projectiles that were launched from a 2-stage light-gas gun [2]. The projectile used for SOCIT4 test was an aluminum sphere and the one used in the DebriSat test was an aluminum cylinder. For the DebriSat test, an impact speed of approximately 7 km/s, on the order of orbital speeds in LEO, was achieved [6]. SOCIT4 and DebriSat both achieved energy to mass ratios (EMR) well above the 40 J/g that is considered as catastrophic, resulting in tens of thousands of fragments. The EMR of DebriSat was 235 J/g, which was three times greater than SOCIT4's 81 J/g. Details of the two impact tests are compared in Tab. 2.

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*Table 2. DebriSat versus Transit (SOCIT) on different target parameters and objects used [6]*

| Parameter | Transit (SOCIT) | DebriSat |
|---|---|---|
| Target mass (kg) | 34.5 | 56 |
| MLI, solar panel | No | Yes |
| Projectile | Aluminum sphere | Aluminum hollow cylinder |
| Projectile diameter (cm), mass (g) | Diameter: 4.7<br>Mass: 150 | Diameter: 8.6<br>Mass: 570 |
| Impact speed (km/sec) | 6.1 | 6.8 |
| EMR (J/g) | 81 | 235 |

Both impact tests utilized foam panels to capture fragments but were configured differently. The foam panels were organized in three sections of the chamber, up-range, side, and down-range. The up-range is the area closest to the gas gun, the side surrounds the satellite, and the down-range is the area furthest from the gas gun. For the SOCIT4 test, only 65% of the satellite's projected area was covered with foam panels, while 100% of the satellite's projected area was covered for DebriSat. The panel configurations for each test are shown in Fig. 1.

For SOCIT4, the foam panel stacks were mounted on plywood inside the chamber and its ten layers consisted of varying densities (0.06, 0.096, and 0.192 g/cm$^3$). Combined, the total thickness of each stack was 25 cm [2]. The foam was comprised of carbon dioxide blown, toluene disocyanate (TDI)/ polyester rigid polyurethane. Five digit labels were created as identifiers for each foam panel with numbers identifying the test, stack, layer, row, and column (e.g. 42111). This identifier was later used during fragment extraction from the foam panels.

Similarly, DebriSat had stacks of foam panels that varied in densities (0.048, 0.096, and 0.192 g/cm$^3$). The side and up-range stacks consisted of 6-7 foam panels with stack thickness of up to 30 cm. Down-range had stacks of 14 panels with thicknesses of 60 cm. These panel compositions were different from SOCIT4 and were comprised of a polyurethane and lexan mix to prevent the fragments from traveling through the panels as easily and provide more structural rigidity [1]. Each panel was given an identification label with information such as test number, location in the test chamber, row number, sub-row designations, and column number (e.g. 2F-122). In addition, foam panel stacks were each a different color, and had different patterns in order to make it easier to distinguish if the labels are not clearly visible. This information is utilized to identify where individual fragments were collected/extracted from.

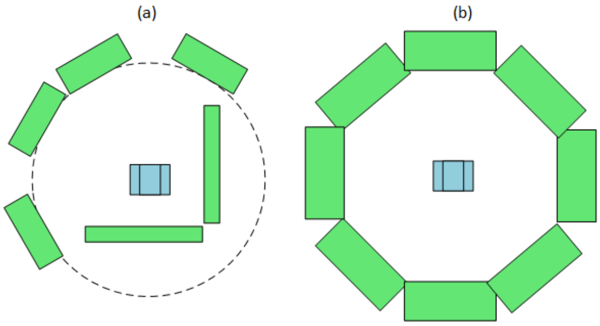

*Figure 1. Downrange view of foam panel configuration of SOCIT4 (a) and DebriSat (b) with green being the foam panels and blue the target satellite*

During the hypervelocity impact tests, various types of equipment were utilized to capture and record data during the impact tests. SOCIT4 used many optical systems including front-lit laser cameras and a high-speed motion picture camera, as well as spectrometers, radiometers, flash X-ray sources, and passive capture of intact fragments. Whereas, the diagnostic equipment used in DebriSat were: X-ray systems with a two-microsecond interval between frames, high speed charge-coupled device (CCD) cameras, a high-speed color video camera, a high-speed infrared imager, an ultraviolet(UV) - visible spectrometer, witness plates, small sample collection stubs, piezoelectric sensors, and gas sampling bottles [2]. The X-ray systems were used to record the projectile's trajectory. The CCD cameras, high-speed video camera, and high-speed infrared imager captured footage of the impact. Piezoelectric sensors were installed into DebriSat to measure shock wave propagation. The UV-Visible spectrometer gathered spectral data of the flash of the impact. Witness plates and the collection stubs were used to collect material that was deposited on the debris due to the impact. Gas sampling bottles used to collect the smoke from the impact. DebriSat utilized newer technologies to gather more information about the impact compared to SOCIT4.

All in all, while SOCIT4 and DebriSat may have used the same test facility for their hypervelocity impacts, the experiments themselves employed different configurations and tools to achieve unique results. The layout and composition of the fragment capture systems and the projectiles were dissimilar, as well as the observational and diagnostic equipment. Note that the DebriSat's impact reached a much greater energy to mass ratio of 235 J/g to SOCIT4's 78 J/g. The increase in energy coupled with DebriSat's unique, modern design yields impact data much more comparable to the current conditions of collisions in orbit.

## 3 EXTRACTION OF FRAGMENTS

The SOCIT4 and DebriSat experiments used different methods to manually extract fragments from their respective fragment capture systems. SOCIT4's foam panels post-impact activities were performed by two organizations, the General Research Corporation (GRC) and Kaman Sciences, while DebriSat's post-impact activities are performed at the UF.

The GRC was the first to extract the fragments for the SOCIT4 experiment. Many fragments were found on the floor of the test chamber and the largest fragments found on the floor (111 in total) were cataloged in a database and given an identification number. The GRC cut the foam panels into 30 cm by 30 cm blocks and assigned a block number to add to the foam panel label. Then, the blocks were completely reduced using a high-pressure water jet to expedite the process. Fragments were separated through a series of sieves with wire mesh areas from 16 mm to 1 mm squared. What remained in each sieve was bagged together and labeled by their block number, instead of individually labeling each fragment. Thus, only an estimate of the number of fragments per block were recorded. In a reexamination of GRC's original data, Kaman Sciences included new information, such as an official number of fragments in each block, its entry angles, and the material information.

Kaman Sciences had two methods to extract the fragments in the remaining unreduced foam panels. The first method involved cutting the 30 cm by 30 cm blocks from each panel further sectioned into one-fourth blocks. This helped make extracting fragments easier than working with a 30 cm by 30 cm blocks. The second method involved inspecting the most heavily impacted panels via X-ray images. X-ray images were used to count and tabulate the number of fragments that were not visible to the naked eye. Fragments were not extracted post X-ray.

DebriSat fragments are also manually extracted from the foam panels. However, a key difference between SOCIT4 and DebriSat's extraction of fragments is that DebriSat's follows a systematic process. The recovery and characterization of DebriSat fragments is done in three processes: detection, extraction, and characterization, all shown in detail in Figure 2.

Detection begins with the preparation of the foam panels for X-ray imaging by collecting loose and embedded fragments that are visibly detected on the surfaces and in noticeable entry points of the panels. An aluminum grid is used to define a coordinate system as shown in Fig. 3. This coordinate system is used to specify the location of the fragments (both embedded and loose) and is used throughout the process for consistency of the data defining fragment location. Once preparation is completed, the panels are X-rayed to identify/locate the embedded fragments that do not have visible entry points. Due to size constraints of the X-ray Computed Topography (CT) scanner, 12 images are captured and stitched into a single mosaic of for each panel. A customized image processing algorithm is applied to the mosaic to detect/locate embedded fragments and identify their locations for extraction

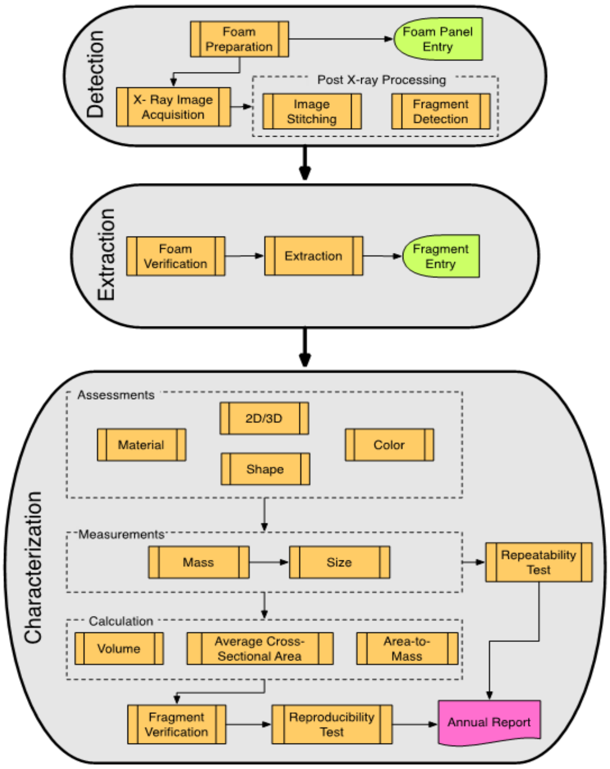

*Figure 2. The Post-Impact Processes of DebriSat [7]*

Once the object detection algorithm X-rayed images are processed, they are used to map locations of fragments on the actual foam panels. Processed X-ray image is projected onto the foam panel and mapping pins are used to locate where the objects are detected. The same coordinate system is used to orient the foam panel to align with the X-ray image. Extraction is performed by using excavation tools on the mapped-out locations of the panel. All fragments extracted out of the foam panels are individually bagged and processed.

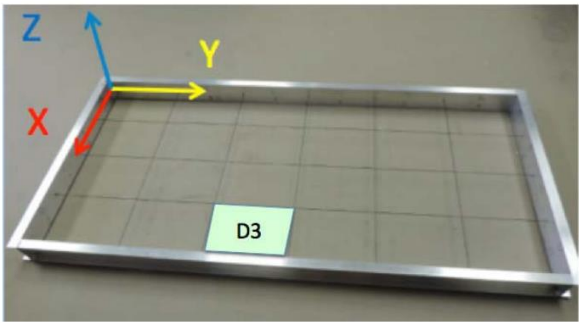

*Figure 3. The coordinate system used on foam panel [8].*

## 4 DATABASE

The respective databases for both projects serve to store and manage collected data during the post-impact phase. This section will go over the differences between the databases developed for SOCIT4 and DebriSat. SOCIT4's database, the Transit Debris Database (TDD), and DebriSat's Debris Characterization System (DCS) are fundamentally different. The TDD was a spreadsheet located on one computer and the DCS is a data management infrastructure. Tab. 3 shows a comparison of several types of data stored by the two databases. Note that not all parameters stored are listed in the table.

*Table 3. Comparison of the TDD and DCS*

| Fragment Parameter | TDD | DCS |
|---|---|---|
| Color | | X |
| Comments/ Notes | X | X |
| Debris ID | X | X |
| Density | | X |
| Images | | X |
| Location | X | X |
| Mass Measurement | X | X |
| Material | X | X |
| Size Measurement | X | X |
| Shape | X | X |
| Velocity | X | |

The TDD consists of information on fragments reduced by both Kaman Sciences and GRC. Kaman Sciences uses the information gathered in the database to generate plots of mass, velocity, and ballistic coefficient distribution. Per subject matter experts, there is a total of over 4,600 objects recorded in the database.

Building off the TDD, the DCS consists of information on each fragment recovered as well as information on the foam panels [9]. Images of each fragment are one of the distinctions between the two databases. For the DCS, depending on the size of the fragment there can be up to 128 images stored for each fragment. The number of fragments to be recovered from DebriSat was initially estimated to be around 85,000 fragments [9]. However, as of February 2017, over 126,000 fragments are collected and recorded in the database. For the estimated 85,000 fragments and assuming that only 10% require 128 images, the total memory storage required would be about 6 terabytes of data which will only increase given the present data [9]. The capacity to handle the amount of data involved with DebriSat ruled out the use of a simple spreadsheet. A more powerful tool such as an updating data management service and a systematic approach to tackling the characterization of each fragment was necessary.

The DCS consists of a user interface front-end and a MySQL backend for data storage. MySQL is an open-source, mobile database solution used as the foundation of the back-end of the DCS. InnoDB tables are utilized as the format for the database because of its high performance with write-intensive commands such as inserting and updating information. Along with the fragment information, the DCS edits and updates the entry for a fragment after every processing step is completed and a revision number is added to track the edits to the fragment entries. Each revision is also time-stamped to aid in tracking the various edits. Once all of the data fields for each fragment entry have been populated, the entry is verified for accuracy. The back-end of the DCS is the primary result of the DebriSat experiment [9].

Another objective of the DCS is to ensure the security of the fragment information stored within it. The DCS stores periodic backups of its data every day to a remote location on the UF campus. The physical hard disks are in a redundant array configuration which uses five separate disks to create one large virtual hard drive and distributes information across all disks. This allows for recovery of data should a disk fail [9].

## 5 CHARACTERIZATION

The characterization process encompasses the measuring techniques for determining the defining features of individual fragments, e.g. size, mass, shape, etc. All of SOCIT4's fragment characteristics were determined manually; human inspections and measurement by hand. On the other hand, DebriSat utilizes a combination of human input and automation to increase accuracy in measurements while reducing fragment handling. Qualitative characteristics, such as material, shape, and color are determined via human inspection. Quantitative characteristics, such as mass

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and size, are measured with balances and imaging systems, respectively. Derived parameters such as characteristic length, average cross-sectional area, area-to-mass ratio, volume, and bulk density are obtained from these measured parameters. The measurement systems include a user-friendly graphical user interface (GUI) [7]. DebriSat builds upon many of the techniques used in SOCIT4's characterization process, while focusing on more rigorous procedures. The information derived from the characterization process is crucial for the analysis of the impact test and the update of the satellite breakup models. Therefore, a rigorous procedure is necessary for the accuracy and integrity of the data.

### 5.1 Materials

SOCIT4 identified the material via visual inspection and categorized material assignment into six categories as shown in Tab. 4 [4]. Other is defined as an unidentifiable material.

Unlike SOCIT4's six materials, DebriSat's material assignments include fourteen categories and are also listed in Tab. 4. Another notable difference is DebriSat only assesses the material that clearly dominates the overall fragment, while SOCIT4 tries to visually account for all the material the fragment is composed of. Like SOCIT4, the material assessment in DebriSat is done by visual inspection. Efforts are made to identify material by calculating its bulk density after mass and size measurements are taken.

### 5.2 Shape

Shape is closely associated with material composition due to deformations from the impact being dependent on the strength of the material. SOCIT4 identified nine shapes through visual inspection. The shapes are listed in Tab. 4. The curled plates consisted of plastic/phenolic or aluminum. The mid-sized fragments such as chunks, flakes, and boxes were hard-plastic or aluminum. The smaller nugget shapes were usually hard plastic and some aluminum. Very little steel and copper fragments were found. [4]

The shape is also determined via visual inspection for DebriSat. This shape information will mainly be used in hydrocode modelling to yield information to orbital debris propagation, optical, and radar research. There are six shape categories and they are listed in Tab. 4. Many of these shapes are based off input from the SOCIT tests and subject matter experts. The hydrocode modelling is time consuming and require multiple iterations for simple shapes. The shapes of DebriSat are grouped in many cases because of the limitations with the modelling and to allow a qualitative and visual assessment. The new shape categories introduced by DebriSat are a result of the different materials used in the design of the satellite such as MLI, CFRP, kevlar, etc. [7].

*Table 4. List of Different Characteristics for SOCIT4 and DebriSat [4, 7]*

| | SOCIT4 | DebriSat |
|---|---|---|
| Material | • Al<br>• Copper<br>• Fiberglass<br>• Plastic<br>• Steel<br>• Other | • Al<br>• CFRP<br>• Copper<br>• Epoxy<br>• Glass<br>• Kapton<br>• Kevlar<br>• MLI<br>• Printed circuit board (PCB)<br>• Plastic<br>• Solar Cells<br>• Silicon<br>• Steel<br>• Titanium |
| Shape | • Box<br>• Box and plate<br>• Curled plate<br>• Cylinder<br>• Flake<br>• Flat plate<br>• Nugget<br>• Sphere<br>• Other | • Bent plate<br>• Bent rod/needle/cylinder<br>• Flat plate<br>• Flexible<br>• Nugget/parallelepiped/spheroid<br>• Straight rod/needle/cylinder |
| Color | None | • Black<br>• Clear<br>• Green<br>• Gold<br>• Light blue<br>• Magenta<br>• Orange<br>• Purple<br>• Red<br>• Royal blue<br>• Silver<br>• White<br>• Yellow |

### 5.3 Color

SOCIT4 did not record color as a parameter associated with fragments. DebriSat, however, uses color as one of the characteristics. To correlate fragments to an initial position within DebriSat, all aluminum components were anodized with different colors depending on their location within the satellite. Anodized aluminum colors are shown in Fig. 4. The colors used in DebriSat are listed in Tab. 4.

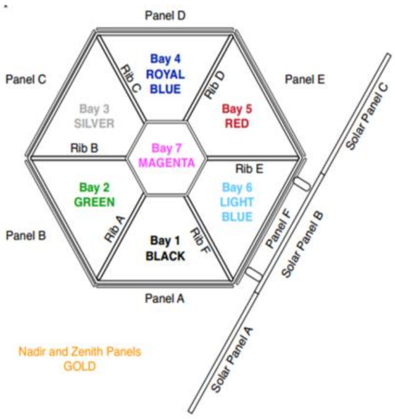

*Figure 4. DebriSat Color Assignment*

### 5.4 Mass Measurement

Mass measurements are another important characteristic necessary to both experiments. The most notable difference in the mass measurement methods were SOCIT4's grouping of fragments that were not one of the 111 largest fragments, and measuring each group as a singular entity. In contrast, DebriSat measures the mass of every individual fragment recovered.

SOCIT4's methodology was to sort the recovered fragments through sieves and group them together based on sieve size into common size bins. Afterwards the total mass of these subsets was recorded. This was a way to track the total satellite mass collected. The only individual fragments that were mass measured were the 111 largest fragments.

DebriSat on the other hand measures the mass of every individual fragment. The minimum fragment size of 2 mm will yield extremely small mass values, some in microgram range. Thus, a micro mass balance with a microgram resolution is used to measure the masses.

### 5.5 Size Measurement

Characteristic length is a necessary feature to calculate for each fragment because it is fundamental data that is used in standard breakup models [2]. It is defined as the average of the fragment's largest three orthogonal dimensions [9].

DebriSat and SOCIT4 used different methods to determine the characteristic length. As noted previously, SOCIT4 grouped together similar sized fragments. The X-Y-Z dimensions of the fragments, or sets of fragments, were determined by following NASA's method of "projected dimensions". In this method, the fragments are measured at planes that show the longest dimension of the fragment [4]. These dimensions were manually measured for the first 111 largest fragments recovered and a few others that were over 0.5 grams in mass. Using these general dimensions, the characteristic length was calculated for each database entry where applicable.

DebriSat has collected a substantial amount of fragments that are needle-like or flat plate-like where the heights can be considered negligible when compared to their other dimensions. Thus, fragments were defined as either two dimensional (2D) or three dimensional (3D). Size characterization systems were developed to provide accurate size measurements. The systems consisted of two automated imaging systems, a 2D imaging system and a 3D imaging system. Both imaging systems use cameras for object image acquisition and create point clouds representative of the fragments. Point clouds are graphical sets of data points that represent the surface and projections of an object. The 2D imaging system utilizes an edge detection algorithm to generate a 2D point cloud. From the point clouds, the three largest orthogonal dimensions are extracted. These dimensions are averaged to calculate the characteristic length. The 3D imaging system utilizes a space-carving algorithm to create a 3D point cloud. In addition to the three largest orthogonal dimensions, the volume and average cross-sectional area are also computed for 3D fragments. Both systems have automated size measurements to accelerate the processing time to measure hundreds of thousands of fragments. The automated size measurements reduce potential fragment damage involved with manually measuring them.

## 6 CHALLENGES ENCOUNTERED

This section explores how DebriSat has matured over time due to unforeseen challenges. The challenges presented correspond only to the post-impact processing activities of the DebriSat project.

### 6.1 Procedures

Data collection for this type of experiment is a meticulous and often time-intensive effort, always requiring improvements. DebriSat built its data collection procedures based off SOCIT4's procedures, however, due to the larger anticipated scale of data management associated with DebriSat, much of the methods required a different approach. Many challenges encountered are related to collection and characterization of fragments down to 2 mm in length.

It became evident during the early stages of fragment collection that the initial tools and procedures had to be updated. One item quickly replaced was the type of bag used for storing and transporting fragments. Small plastic bags were initially used but were more conductive of static forces that made handling fragments problematic. The static force would occasionally prevent the fragment from being inserted into the bag, even sometimes launching the fragment from the tweezers. This posed a large risk for fragment damage and thus anti-static bags were introduced. In addition, tables were customized for the extraction process. The initial tables used stood very low, forcing many of the technicians to hunch over. Long sessions of extraction were extremely uncomfortable for them. To address this, ergonomic extraction tables with an adjustable height were introduced.

The characterization process also had challenges associated with the microbalance used for mass measurement of fragments close to the 2 mm minimum. The microbalance was sensitive to temperature, vibrations, and airflow within the measuring station which influenced the measurement. So, a granite table was introduced to reduce vibrations and an enclosure was needed to restrict airflow from entering the microbalance.

### 6.2 Human Error and Automation

When dealing with a very large number of fragments and their corresponding data, the effect of human error becomes significant. The largest cause of human error has been the result of user input involving the recording of information into the DCS. Thus, many automation efforts were produced to minimize these errors in the mass and size measurements. For example, Graphical User Interfaces (GUIs) are used to minimize human input and automate the measuring processes for the mass balances and imaging systems. These are helpful in terms of efficiency, but each process cannot be automated in characterization due to the information not being completely quantitative. Qualitative information would include material, color, and shape of the fragments. To reduce human bias, multiple references and examples have been provided to improve objectivity.

Another challenge was the object detection algorithm. The initial object detection algorithm would occasionally miss fragments or mark nonexistent fragments on stitched X-ray images. This led to an increase in processing time during extraction. Efforts have been made to improve the object detection algorithm to reduce such errors.

## 7 CONCLUSION

The DebriSat experiment has benefitted significantly by leveraging lessons learned from the SOCIT4 experiment along with the technological advancements that have occurred during the time between the two experiments. DebriSat will take longer to complete its fragment processing compared to SOCIT4, which was accomplished in 2 years, because of the meticulous and systematic processes in place. The meticulous and systematic processes help increase accuracy and ensure the integrity of data is maintained. Ongoing efforts are being made to increase efficiency for the DebriSat fragments. The two hypervelocity impact experiments represent two ages of satellite technology and, together, demonstrate the continuous efforts to improve the experimental techniques for fragmentation debris characterization.

## 8 ACKNOWLEDGEMENT

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