

# Data Acquisition, Management, and Analysis in Support of the Audiology & Hearing Conservation and the Orbital Debris Program Office

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## Abstract

My internship at Johnson Space Center, Houston TX comprised of working simultaneously in the Space Life Science Directorate (Clinical Services Branch, SD3) in Audiology and Hearing Conservation and in the Astromaterials Research and Exploration Sciences Directorate in the Orbital Debris Program Office (KX).

The purpose of the project done to support the Audiology and Hearing Conservation Clinic (AuHCon) is to organize and analyze auditory test data that has been obtained from tests conducted onboard the International Space Station (ISS) and in Johnson Space Center's clinic. Astronauts undergo a special type of auditory test called an On-Orbit Hearing Assessment (OOHA), which monitors hearing function while crewmembers are exposed to noise and microgravity during long-duration spaceflight. Data needed to be formatted to assist the Audiologist in studying, analyzing and reporting OOHA results from all ISS missions, with comparison to conventional pre-flight and post-flight audiometric test results of crewmembers.

Orbital debris is the #1 threat to manned spacecraft; therefore NASA is investing in different measurement techniques to acquire information on orbital debris. These measurements are taken with telescopes in different parts of the world to acquire brightness variations over time, from which size, rotation rates and material information can be determined for orbital debris. Currently many assumptions are taken to resolve size and material from observed brightness, therefore a laboratory (Optical Measurement Center) is used to simulate the space environment and acquire information of known targets suited to best model the orbital debris population. In the Orbital Debris Program Office (ODPO) telescopic data were acquired and analyzed to better assess the orbital debris population.

## Nomenclature

AuHCon	=	Audiology and Hearing Conservation
CCD	=	Charge Coupled Device
CCFP	=	Cerebral Cochlear Fluid Pressure
dB	=	Decibels
EMR	=	Electronic Medical Record
FFT	=	Fast Fourier Transform
HST	=	Hubble Space Telescope
ISS	=	International Space Station
JSC	=	Johnson Space Center
LEO	=	Low Earth Orbit

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MLI	=	Multi-Layer Insulation
MUTS	=	Multi-Utility Telescope System
NASA	=	National Aeronautical and Space Administration
OOHA	=	On-Orbit Hearing Assessment
ODPO	=	Orbital Debris Program Office
OMC	=	Optical Measurements Center
R/B	=	Rocket body
TMD	=	Tympanic Membrane Displacement
TTS	=	Temporary Threshold Shift
USAFA	=	United States Air Force Academy

## I. Audiology and Hearing Conservation: Introduction

The NASA Johnson Space Center's (JSC) Audiology and Hearing Conservation (AuHCon) clinic provides clinical, administrative and research support in NASA's efforts to prevent noise-related hearing loss among its personnel such as astronauts, related flight employees, as well as ground-based NASA employees and contractors. A hearing conservation program (HCP) is in place at JSC that is intended to not just comply with requirements of federal regulatory safety and health standards, but offer the best practices known in the hearing conservation community regarding personal hearing protection, noise monitoring and control practices, health education, early detection of hearing loss through audiometric monitoring and follow-up and other services.<sup>1</sup>

## II. Hearing Conservation in Spaceflight

The JSC audiologist works in collaboration with JSC's Acoustics Working Group and Crew Surgeons to limit noise crew noise exposure on ISS through engineering controls and medical monitoring. Hearing protective devices are evaluated, recommended, and fitted for use in aircraft during NASA training, as well as for use in space vehicles in space flight missions. With regards to long-term spaceflight, the Audiology and Hearing Conservation is involved in researching possible risks to human health when crewmembers spend extended periods of time in microgravity. In addition, audiology adds an important component to teams focusing on safety and health standards and design of space vehicles for the next generation of NASA space missions.

The main focus of AuHCon is testing the human hearing sensitivity by determining the hearing threshold during audiometric testing. A hearing threshold is the softest level detected by a listener in more than 50% of presentations. During audiometric testing, bracketing techniques are used by testing in 5dB increments. With this in mind, a test/re-test variability system is used where a 5dB change in hearing is not considered significant. Whereas conventional audiometry can be used to reveal a permanent hearing threshold shift (by comparing postflight data to preflight data), only an OOHA can be performed during the actual space mission, therein revealing a temporary threshold shift during the mission. A temporary threshold shift can lead to a permanent threshold shift if acoustic countermeasures are not taken.<sup>1,2</sup>



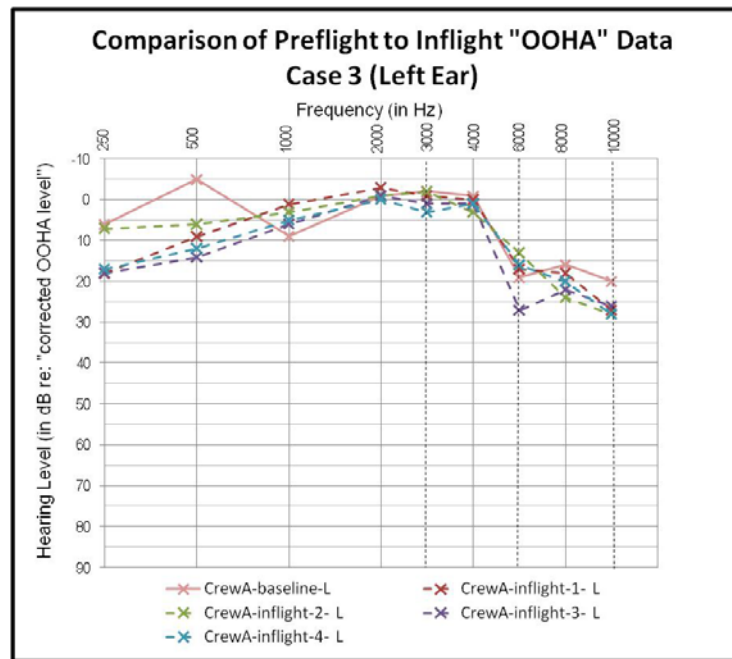
**Figure 1.** A crewmember performing the OOHA test during Expedition #20. Insert ear monitors are being worn underneath the visible Bose active noise reduction headset, as the crewmember uses a software program on his computer to assess his hearing sensitivity.

Credit: <http://www.nasa.gov/centers/johnson/slsd/about/divisions/spacemed/facilities/audiology.html>

### III. On-Orbit Hearing Assessment

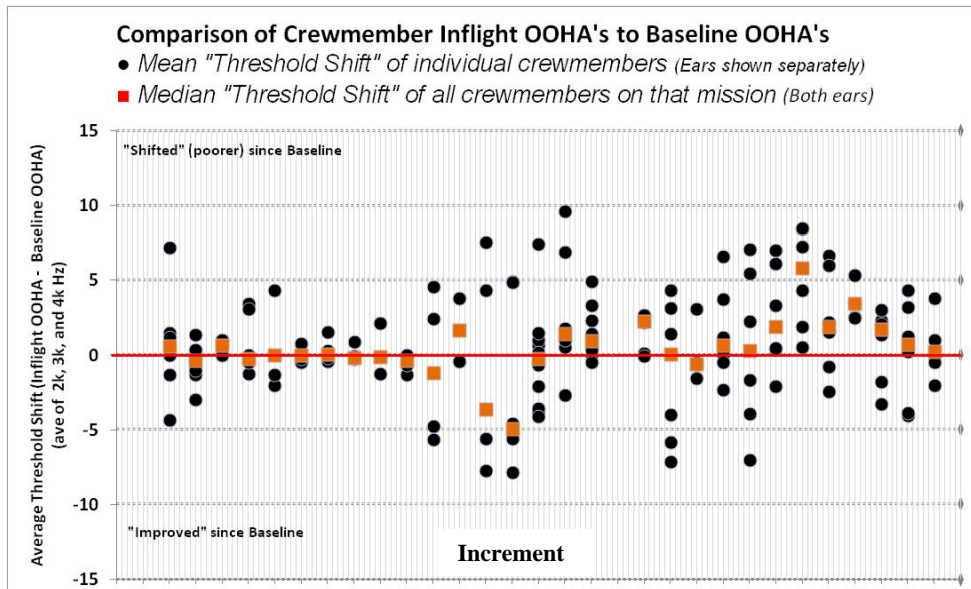
An OOHA is done within the first 14 days of flight on the ISS, and then every 60 days thereafter, to assess the peripheral hearing sensitivity of crew members while living on the ISS. This test usually takes around thirty minutes and uses EarQ software on the Medical Equipment Computer (MEC) (or, more recently, the Space Station Computer, or SSC).

Once a test was completed on-orbit (as seen in **Fig. 1**), the OOHA data were downlinked to JSC ground communications. In the AuHCon Clinic, I received the data as a MATLAB file and input the data into the Electronic Medical Record (EMR) for the audiologist. OOHA data are obtained with unique hardware (not audiometers) are therefore considered by audiologist to be of an unconventional nature. Therefore, the raw OOHA data had to be corrected, using normative data, to be roughly equivalent to audiometric thresholds that would be obtained with audiometers calibrated to ANSI S3.6 (1996). This correction process was completed when transferred to the EMR. At this point, the new test was put on hold for the audiologist's analysis. I assisted in keeping track of the date and results of each OOHA taken, as well as baseline OOHA's in a Microsoft Excel database. Since a baseline OOHA was obtained preflight, on the ground, using similar hardware and testing conditions of an inflight OOHA test, comparisons of baseline and inflight OOHA test results can be used to identify significant threshold shifts (e.g., those greater than 2 standard deviations re: normative data). The ISS biomedical engineers would then be made aware of the crewmember's results and recommendation by the audiologist. **Fig. 2** shows an example of a possible temporary threshold shift in OOHA #3, which was resolved to be within limits by OOHA #4. Nearing the end of my internship, over 380 OOHA's were in the tracking database, gathered from ISS increments 1-30.



**Figure 2. OOHA graph, comparing in-flight tests to pre-flight baseline for the person's left ear.** The x-axis shows the frequencies being tested, in relation to the hearing level in dB on the y-axis. The solid line is the baseline (obtained preflight, on the ground), and each in-flight OOHA test shown as a dotted line.

I also designed a new way to plot OOHA results from individual increments, using a format that could be directly compared to acoustic noise dosimetry results from each increment. My plot depicted comparisons of inflight OOHA's to preflight baseline OOHA's (by averaging thresholds at 2k, 3k and 4k Hz, which are conventionally used to identify noise-related hearing loss). In **Fig. 3**, data are plotted as a positive value, identifying cases of poorer inflight hearing sensitivity since the baseline. The red line represents no shift since the baseline, whereas an "improvement" since the baseline is represented by data plotted with negative values. As seen in **Fig. 3**, the mean "threshold shifts" of individual crewmember ears are plotted as a black dot. As there are typically three crewmembers per increment, there are about six black dots for each increment. The median of each increment's OOHA data was then determined and plotted as an orange square.



**Figure 3.** This plot shows a comparison of hearing "threshold shifts" (when comparing inflight to baseline OOHA's). The horizontal axis of the graph represents different ISS increments. Each increment has an 1) an orange symbol, representing the median of each crewmember's shift. As can be seen, the majority of data points falls with the +/- 5dB accepted range of variability.

#### IV. Collaborative Institutional Training Initiative Certification

The Collaborative Institutional Training Initiative (CITI) was founded in March 2000 as a web-based training program in human research ethics education to all members of the research community. In response to the June 2000 education policy announcement<sup>3</sup>, the collaboration was expanded to include content experts from 10 institutions who provided the content for the first 12 biomedical modules. As per JSC requirements for human research and medical data privacy, I completed the CITI training due to my responsibilities to handle human subject research data appropriately. Topics included, but were not limited to, ethics in human subject research, informed consent, and vulnerable research subjects. With this certification completed, I am now prepared to work with biomedical research, if given the opportunity once again.<sup>3</sup>

#### V. Software Requirements Document for CCFP Analyzer

The Cerebral and Cochlear Fluid Pressure (CCFP) Analyzer is a clinical and research tool based on work by Dr. Robert Marchbanks of Southampton University, Great Britain. Also known as the Tympanic Membrane Displacement (TMD) analyzer, this medical diagnostic device is designed to measure extremely small movements of the tympanic membrane in terms of the air volume displaced by these movements. The CCFP Analyzer uses technology developed for detecting changes in cochlear and intracranial fluid pressures, and has been used in Europe for several years. The CCFP is now being reviewed as a possible noninvasive tool (in lieu of invasive and uncomfortable lumbar puncture tests) for the NASA's Visual Impairment, Intracranial Pressure group's investigation of elevated intracranial pressure. In 2011, another intern in the AuHCon clinic developed a graphical user interface (GUI), to assist in the analysis of data gathered by the CCFP. Johnson Space Center requires a software requirements document for further professional development by Wyle Technology. During my internship, I assisted in the creating of details and rationale for what should be further developed using this software tool. Significant points necessary for further development include integration with the EMR and graphical export settings with default labels in place for outputting a graph from the EMR to another program.<sup>4</sup>

## VI. Audiology and Hearing Conservation: Conclusion

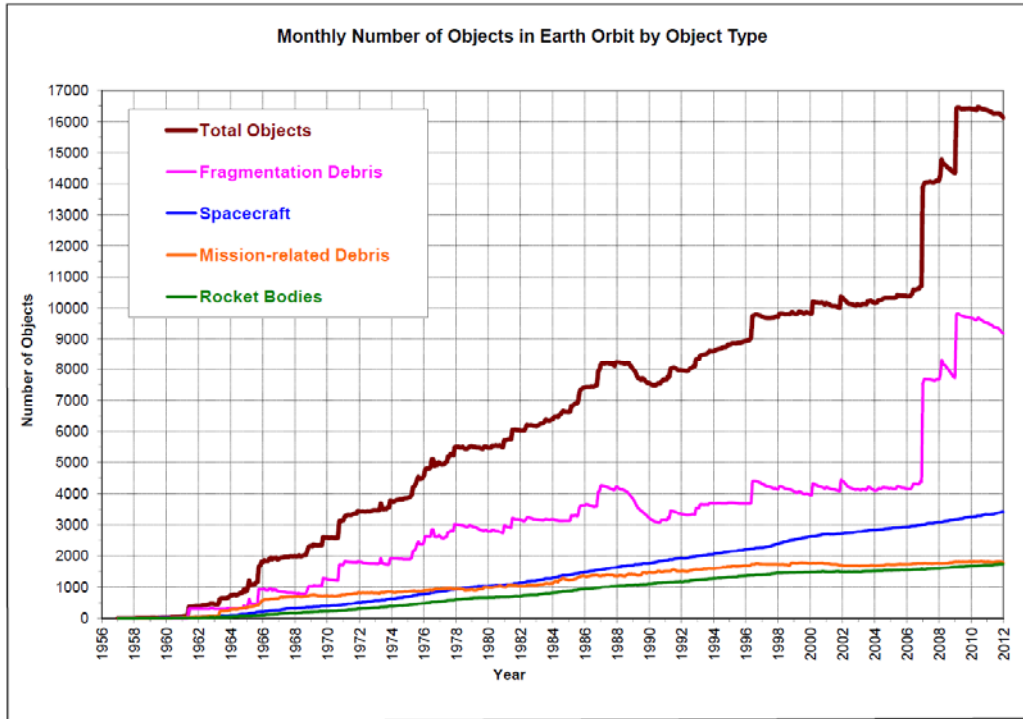
During my time in the Audiology and Hearing Conservation, I produced summary reports of OOHA results from recent ISS missions, with data comparisons to conventional pre-flight and post-flight audiometric test results of crewmembers. I also created new graphics, to depict in-flight shifts (both poorer and improved) from pre-flight tests for during expeditions 1-30. The audiologist used my graphics in his briefings to an international panel of acoustics and medical personnel in Moscow in April 2012. The CCFP software requirements document was sent to Wyle Technology and is ready for further development of the GUI.

## VII. Orbital Debris Program Office: Introduction

The Orbital Debris Program Office (ODPO) focuses on four major areas of research regarding orbital debris. They are measurements, modeling, short-term risk assessments, and reentry analysis. Within the measurements group there are three subcategories, including radar data processing and analysis, optical data collection, processing, and analysis, and in situ measurements and analysis. My work in ODPO primarily focused on data collection, processing and an analysis.

Orbital debris is defined as any human-made object in orbit about the Earth which no longer serves a useful purpose. Examples of such debris include spent spacecraft and upper stages, rocket bodies (R/B), debris intentionally released, debris created as a result of explosions or collisions, solid rocket motor effluents, and tiny flecks of paint.

Orbital debris has been an issue for many years but has only recently come to the attention of the public. Two major in-orbit events in the past decade have reshaped the view of the low Earth orbit (LEO) environment and the necessity of debris removal from it. In 2007, a test by the Chinese government resulted in the Fengyun 1C anti satellite weapon test. The Fengyun 1C was a defunct Chinese weather satellite which was destroyed via a kinetic projectile. This collision is said to have produced 2,841 high-velocity debris objects. This is undisputedly the largest amount of debris created by any one space mission to date. Two years later, the first hypervelocity collision of two satellites occurred in Earth orbit. These collisions are still affecting space operations today. As seen in **Fig. 4**, the fragmentation debris population increased by roughly 45% between 2007 and at its peak in 2009 due to these two LEO events. As recently as March 2012, these collisions have affected the operations of the International Space Station (ISS). The crew members had to take shelter as a piece of Cosmos 2251 passed by the facility.<sup>5,6</sup>



**Figure 4. Monthly Number of Cataloged Objects in Earth Orbit by Object Type.** This chart displays a summary of all objects in Earth orbit officially cataloged by the U.S. Space Surveillance Network. Notice the spikes in number of objects in 2007 and 2009 due to the events mentioned above. “Fragmentation debris” includes satellite breakup debris and anomalous event debris, while “mission-related debris” includes all objects dispensed, separated, or released as part of the planned mission.

Credit: <http://orbitaldebris.jsc.nasa.gov/newsletter/pdfs/ODQNv16i1.pdf>

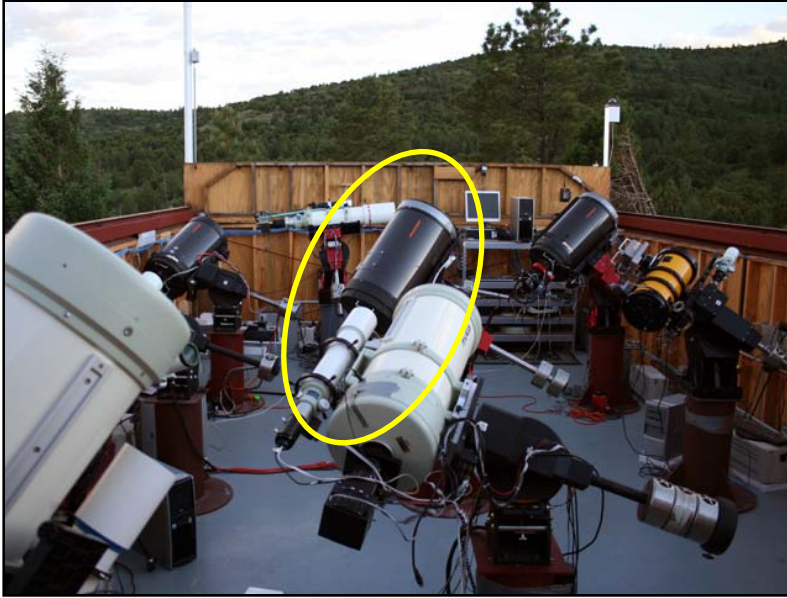
### VIII. Early Stages

These recent events have raised the idea of active debris removal (ADR) as a priority of the current administration. Using modeling tools and measurements of intact, massive targets, the ODPO is researching the possibilities of ADR to better preserve and protect the environment in the future.<sup>7</sup>

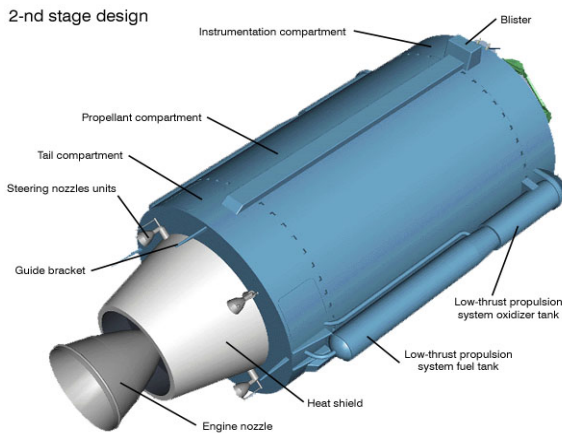
The first steps towards limiting orbital debris is to acquire data detailing potential targets’ tumble rates to plan and develop proximity operations for potential future ADR operations. The goal is to determine rotation rates of observed rocket bodies from multiple telescope sources. Eventually this could lead to helping to remediate the LEO environment from these hazardous by-products of spaceflight.<sup>6, 8</sup>

### IX. Rocket Body Lightcurve Research

The data acquisition of R/B lightcurve was completed by remotely observing the New Mexico Skies Multi-Use Telescope System (MUTS) via an on-site software system at JSC. Located in Mayhill, New Mexico, the ODPO shares time with Marshall Spaceflight Center (MSFC) on the Orion 80mm refractor telescope on a German Equatorial Mount as seen in **Fig. 5**. Attached to the telescope is a WATEC H2 Ultimate camera with paramount used to acquire imagery of the target. Targets primarily consist of Cosmos 3-M secondary stage rocket bodies known as SL-8s. During observations, data would also be taken on a set of standard stars to acquire accurate measurements for brightness comparisons.



**Figure 5.** Circled in yellow is the 80mm Orion Refractor telescope being used by ODPO for R/B data acquisition.  
Credit: <http://www.nmskies.com/>



**Figure 6. Graphic of SL-8 rocket body.** These targets are being observed via NM Skies telescope. Scaled models (1:48) are being used for laboratory testing in the Optical Measurements Center.  
Credit: <http://danielmarin.blogspot.com/2010/04/lanzamient-o-kosmos-3m-parus-99.html>

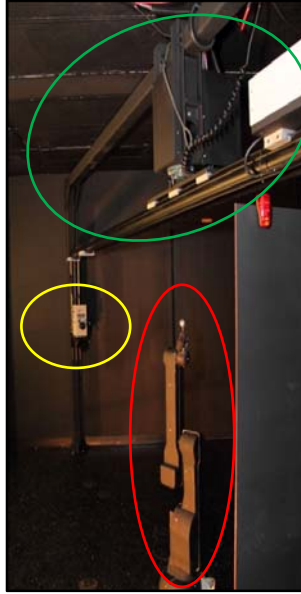
The raw data acquired was then processed using software programs Virtual-Dub and Li-Movie. Virtual-Dub split the data into 2GB segments. This process was necessary to utilize Li-Movie for eliminating the surrounding background noise out of the captured data. The processed data was output as text file and converted to a Microsoft Excel spreadsheet. The processed data were then manually plotted in Microsoft Excel. Time constraints and convenience did not allow for more efficient methods in converting the processed data into lightcurve plots.

Determining the rotational period of the target used a Fast Fourier Transform (FFT) technique. A software program called PERANSO was used for period analysis, which provides different techniques to resolve an object's period in units of cycles per day (c/d). Three specific algorithms were used on the data: ANOVA, Bloomfield, and CLEANest. ANOVA, or Analysis of Variance, improves peak detection sensitivity and reduces alias periods. The Bloomfield technique emphasized the Least Squares Standard Technique to calculate a power spectrum. The CLEANest method is effective for detecting and describing multi periodic signals. For the data collected, the CLEANest algorithm is helpful as some targets showed indications of a number of rotations during a single pass.<sup>9</sup> Preliminary determination of rotation rates on a select set of R/Bs were provided and will be used as a comparison to the scaled model simulations obtained in the Optical Measurements Center (OMC).

## X. Optical Measurements Center (OMC)

One tool being used in the research of ADR is the OMC. The purpose of the OMC is to produce light curves representative of the orbital debris environment to obtain a better understanding of their properties and evaluate potential risks. To better characterize and model optical data acquired from ground-based telescopes, the OMC attempts to emulate illumination conditions seen in space using equipment and techniques that parallel telescopic

observations and source-target-sensor orientations. Equipment in the OMC, as seen in **Fig. 7**, included a 75-watt Xenon arc lamp, used as a solar simulator; a Santa Barbara Instrument Group (SBIG) CCD camera with standard Johnson/Bessel filters; and a robotic arm, used to simulate an object’s position and rotation. Along with these instruments, a robotic arm is used to orient and rotate objects in simulating an object’s orbit or rotational period.<sup>10</sup> During my internship, the OMC was in the process of equipment calibrations. These calibrations included: rotary arm phase angles, light source collimation, defining accurate phase angles that can be measured, and acquiring imagery data to determine the exposure ratios between different filters.

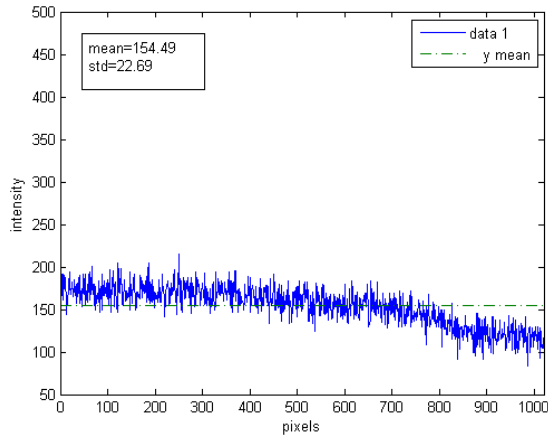


**Figure 7.** Shown above is the OMC with calibrated instruments. The 75 watt Xenon arc lamp is circled in yellow, robotic arm is circled in red, and the rotary arm is circled in green. SBIG CCD camera is not pictured. The OMC attempts to simulate space illumination conditions with these instruments.

In the process of rotary arm calibrations, the goal was to determine whether the software output from LABVIEW was accurate by multiple trials. This process was completed by measuring voltage in relation to phase angle and calculating the offset. This determined if the voltage was linear. The calibration data was collected in three separate trials in both clockwise and counterclockwise directions. Minor inaccuracies were discovered initially. Measuring physical angles in 5° increments subtended by rotary arm vs. software output, results indicated a difference of incorrect gain of 6° between 0° and 360°. The rotary arm’s 0° position which should align with camera was offset +10° required modifying offset. Voltage input for each specific phase angle never differs more than 0.4% and was determined to be a linear relationship. The solutions to these problems were confirmed as effective as the difference between 0° and 360° is now indistinguishable and repeatable; the rotary arm was now in line with the camera at 0°, and the physical angle vs. LABVIEW output was found to stay less than a deviation of 1° in either direction.

In addition, the light source needed to be tested for collimation which was done by scanning along variations of rows and columns using MATLAB and CCDOPS. Testing was done by taking multiple images which verified the pixels were illuminated to the same degree throughout the CCD via 1020x1530 chip. The mean represented as a dotted green line in **Fig. 8** shows a MATLAB matrix detailing the average of illuminated pixels during the test as 164.876 with a standard deviation of 14.6752. In **Fig. 8**, the intensity across the illuminated background is flat (mean 154.9 with a sigma of 14.7), but at around 750 pixels we are now measuring the non-illuminated background via the drop off in intensity and the overall intensity statistics are shown in the plot (both illuminated and non-illuminated).





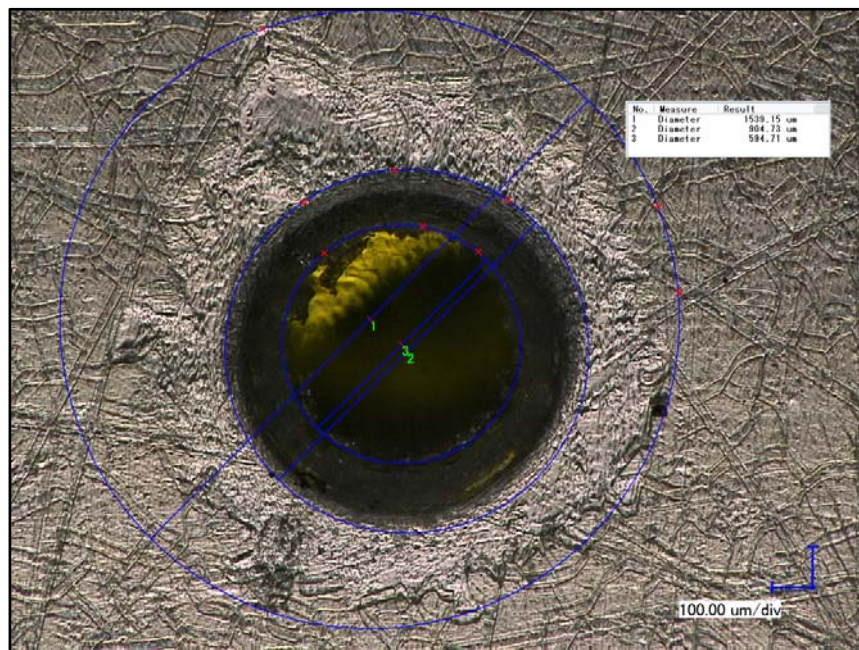
**Figure 8. MATLAB Image shows collimation test results.** Range shows column 1350 and all rows from 1 to 1020. This test details a drop in intensity around 750 pixels with an average intensity of 164.876.

Finally, the maximum exposure on the CCD camera was determined before saturation started to occur. Five standard astronomical filters were used to acquire images of a spectrally flat surface in one second increments. At seven seconds, it was determined using CCDOPS software that the intensity counts had exceeded 50,000 count or analog-to-digital units, thus reaching saturation for this camera.

### XI. Hubble Space Telescope Multi-Layer Insulation Inspection

ODPO received pieces of space flown hardware to observe and analyze for micro-meteoroid and orbital debris impacts. Another project I completed was to use a digital microscope searching for impacts on a sheet of multi-layer insulation (MLI) returned from the STS-125 Hubble Space Telescope (HST) servicing mission.

Two MLI samples were returned from the HST onboard Atlantis in May 2009. The digital microscope was utilized to provide better understanding of in situ environment by providing measurements of the significant diameters of the impact region. The operation can measure impact features of greater than or equal to 100 microns (um) and is capable of reaching 200X magnification. By measuring the impact crater’s diameter and taking multiple images of significant focal points on the target, a three-dimensional image can be created. The data found regarding each crater such as in **Fig. 9** will be compiled to assist in the creation of a model which predicts the expected flux in a given orbit. This could help to develop more advanced outer layers of spacecraft and extravehicular mobility units.



**Figure 9. Image taken of MLI impact.** A blue outline indicates a significant diameter measurement of the impact. Diameter 1 (1539.15um) measures the entire region of the impact. Diameter 2 (904.73um) measures the immediate impact region. Diameter 3 (594.71um) measures the diameter of the inside of the impact region.

## XII. Orbital Debris Program Office: Conclusion

To first consider Active Debris Removal as an option to alleviate such an evident threat from manned spaceflight surrounding Earth, a thorough investigation of the targets must be completed. From the on-going rocket body research, results can determine which rocket bodies have slow rotational periods. Now that all OMC instruments have been tested and calibrated, photometric data on the scaled rocket bodies can begin. The resultant data will be used in collaboration of acquired telescopic data to determine the probable rotation axes of the observed targets. The MLI inspection process improves knowledge about the damage caused by orbital debris and micro-meteoroid impacts on long-duration spacecraft. The images of these impacts will help to calculate predicted flux in a given orbit by developing a numerical model system. Overall, my research has contributed many improvements, such as preparing the OMC and organizing lightcurve graphs for analysis, to the advancement of orbital debris modeling and knowledge of the orbital debris environment.

## XIII. Acknowledgments

The author would like to thank both his mentors, Dr. Richard Danielson and Dr. Heather Cowardin for their guidance and mentorship throughout these projects. He would also like to thank them, along with Dr. Phillip Anz-Meador, for being given the unique opportunity to work simultaneously between two different divisions during the author's internship. The author would also like to thank Jon Read for mentoring on the subject of rocket body research. Overall, the Audiology and Hearing Conservation Clinic, the Orbital Debris Program Office, and the NASA USRP Education Office were all very help during the author's internship and he would like to thank them for their guidance. The author would also like to thank Candy Cordwell and Dr. Majid Jaridi, as well as the complete West Virginia Space Grant Consortium for their assistance, both personally and financially. Also a special thanks to Dr. Warren Myers, Dr. Brian Woerner, and Dr. Duncan Lorimer of West Virginia University who all played a significant part in assisting the author in completing this opportunity. And finally, the author would like to thank Captain Jon McBride. Without this tremendous amount of support, none of this would have been possible.

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