The Role of NASA Engineering & Safety Center (NESC) in Advancing NASA's Earth Science Missions (Past, Present, and Future)

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ABSTRACT

The NASA Engineering & Safety Center (NESC) was established in 2003 to provide an independent technical resource for the resolution of challenging technical problems (through the use of studies, analysis, tests, etc.). Since its inception, NESC has completed nearly 1000 technical assessments for NASA's Human Exploration and Operation Mission Directorate (HEOMD), Science Mission Directorate (SMD), Space Technology Mission Directorate (STMD), and Aeronautics Research Mission Directorate (ARMD). Of the SMD related assessments, several were for the resolution of technical problems, analysis, or studies related to NASA's Earth science missions in various phases of the project from design to operation. Some of the recent examples of NESC technical support for NASA (or NOAA) Earth science missions have been for: Soil Moisture Active Passive (SMAP), Deep Space Climate Observatory (DSCOVR), Cyclone Global Navigation Satellite System (CYGNSS), Ice, Cloud, and Land Elevation Satellite (ICESat-II), Joint Polar Satellite System (JPSS), and the soon to be launched collaboration mission with India, NASA-ISRO Synthetic Aperture Radar (NISAR). In this paper, we outline some of the technical challenges faced by these Earth science missions and describe how NESC contributed to their resolution. The case studies cover a wide range of disciplines involving space lidars, radars, electronics, attitude control systems, as well as Micrometeoroid Orbital Debris (MMOD) risk assessment impact to NASA missions. The efforts include strategies for risk mitigation, technical resolution of challenging problems, and failure root cause investigations combined with lessons learned reports to advance discipline knowledge, enhance NASA capabilities, and avoid future problems.

Keywords: NASA, NESC, NOAA, NISAR, SMAP, DSCOVR, CYGNSS, ICESat-II, Space Lidars, Space Radars

1. INTRODUCTION

The NASA Engineering & Safety Center (NESC)[1] was established in 2003 (after the Columbia accident) to provide an independent technical resource for the resolution of challenging technical problems. The NESC performs value added, independent, technical assessments, testing and analysis for NASA's high-risk projects, from design to operation, to ensure mission success and safety. The NESC's cadre of NASA Technical Fellows and their supporting Technical Discipline Teams drawn from across NASA's field centers, industry, academia, and various government agencies provides a ready resource of technical expertise that can be rapidly applied to critical problems. Since inception in 2003, NESC has completed nearly 1000 technical assessments or support tasks in response to requests from NASA's Human Exploration and Operations Mission Directorate (HEOMD), Science Mission Directorate (SMD), Space Technology Mission Directorate (STMD), Aeronautics Mission Directorate (ARMD), as well as external to the Agency requests. Figure 1 shows the total distribution of accepted and completed technical assessments by NESC.

As seen from the figure, HEOMD related assessments lead the total number of NESC assessments. Examples of technical support of HEOMD programs include the Commercial Crew Program (CCP), Space Launch System (SLS), Orion Multi-Purpose Crew Vehicle (MPCV), International Space Station (ISS), Artemis, and Gateway.

A sizable number of technical assessments are in response to broad agency requests. Some examples of such assessments

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include: “State of Hydrazine Synthesis and Its Potential Impact on Spaceflight Applications”; “Guidelines for an Avionics Radiation Hardness Assurance”; and “Assessment of Spacecraft Passivation Techniques”.

From time to time, NASA also receives requests from external organizations to assist with challenging technical issues. For example in 2010, NESC provided technical support in response to a request from the Chilean government to aid with freeing of trapped Chilean miners.

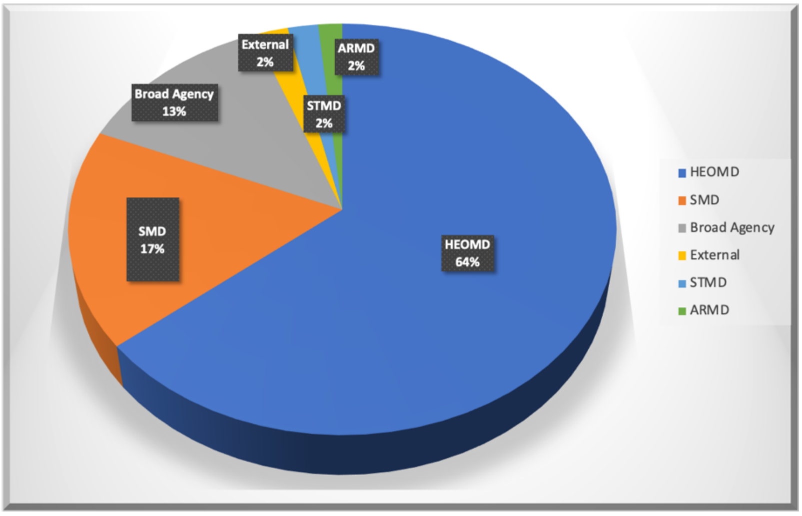

Figure 1. Distribution of NESC completed assessments since NESC inception in 2003.

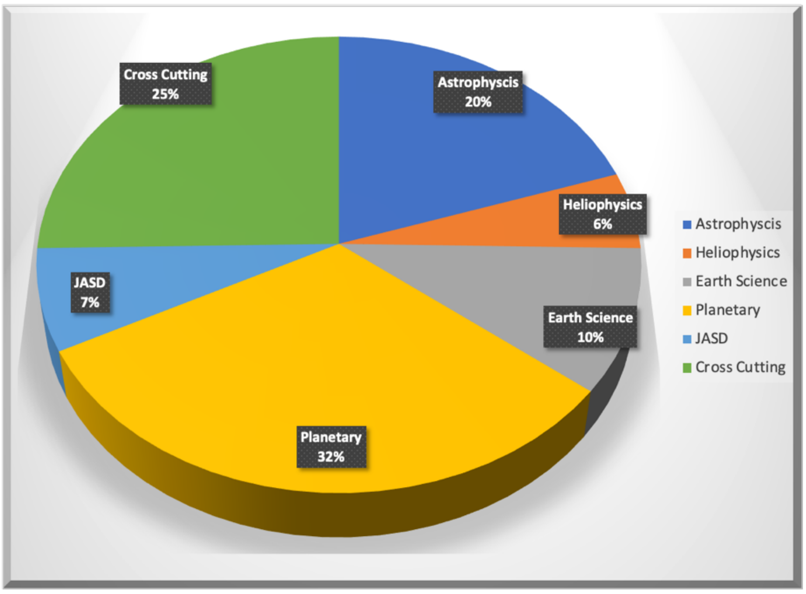

Figure 2. Distribution of NESC completed assessments for NASA SMD since NESC inception in 2003.

The next largest customer of NESC's technical expertise is SMD with a total of 166 SMD related assessments completed as of March 2020. Figure 2 shows the distribution of assessments completed for NASA SMD.

These requests are distributed across Earth Science, Planetary, Astrophysics, Heliophysics, and Joint Agency Satellite Division (JASD) projects. JASD projects cover joint NASA/NOAA projects such as GOES and JPSS. A quarter of the assessments have cross cutting applications across SMD focusing on areas such as spacecraft platforms, launch vehicles, airborne platforms, balloons, robotics, satellite servicing, and cryocoolers.

In this paper, we primarily focus on NESC's technical support of NASA's and NOAA's Earth Science missions, describing some of the technical challenges faced by these projects and describe how NESC contributed to their resolution. In the next few sections, we describe NESC's work for the following projects: Cyclone Global Navigation Satellite System (CYGNSS), Soil Moisture Active Passive (SMAP), Deep Space Climate Observatory (DSCOVR), Joint Polar Satellite System (JPSS), Ice, Cloud, and Land Elevation Satellite (ICESat-II), and the soon to be launched collaboration mission with India, NASA-ISRO Synthetic Aperture Radar (NISAR).

The case studies discussed below cover a wide range of assessments that include strategies for risk mitigation, technical resolution of challenging problems, and failure root cause investigations combined with lessons learned reports to advance discipline knowledge, enhance NASA capabilities, and avoid future problems.

2. CYGNSS

The Cyclone Global Navigation Satellite System (CYGNSS), part of NASA's Earth System Science Pathfinder Program, consists of a group of 8 microsatellite that launched on December 15, 2016. The mission aims to improve extreme weather prediction such as formation and tracking of hurricanes or cyclones. The CYGNSS collection of 8 observatories receive both direct and reflected signals from Global Navigation System (GPS) satellites. The direct signals pinpoint the 8 observatories positions while the reflected signals are used to retrieve the wind speed over Earth's oceans in the tropics where hurricanes are more likely to form.

The CYGNSS project sought NESC's help regarding two technical challenges. We describe them and their resolution in the following sections.

2.1 Reaction Wheel Assembly Design

At the request of the Earth System Pathfinder Program, the NESC supported a technical interchange meeting (TIM) in March 2014 at Blue Canyon Technologies (BCT) to review the design and life-test plans for the reaction wheels intended for CYGNSS. NESC subject matter experts in the areas of space mechanisms, tribology and lubrication, and guidance and navigation control were present. At that time, the reaction wheels intended for CYGNSS lacked space flight heritage and were required to be at a technology readiness (TRL) level of 6. There was a question as to whether the design was at TRL 6 due to a problem with a post qualification vibration test that resulted in a change to the design. Each CYGNSS microsatellite utilizes three reaction wheels for a total of 24 reaction wheels. The large number of reaction wheels and lack of space heritage presented a risk to the mission, with the first flight of the reaction wheels under review to be flown on XACT in the Fall of 2014, just two years before the CYGNSS launch in December of 2016. The NESC team shared lessons learned regarding bearing design, lubrication, reaction wheel operations, and life testing philosophy. Emphasis was placed on the life test plans for CYGNSS and recommendations were advanced, including testing multiple units at CYGNSS flight like conditions (elastohydrodynamic) at flight temperatures in vacuum. In addition, BCT agreed to test a single unit under non-flight-like conditions (sub elastohydrodynamic) at slower speeds and with zero crossings to demonstrate successful operation for future missions. Testing multiple units provided greater confidence in the results than testing a single unit to a factor of two times life, the standard factor employed in life testing of space mechanisms.

2.2 Peak Power Tracker (PPT) Electronic Board

A solar array peak power tracker power electronic converter design intended for the CYGNSS microsatellite group performed well when built up as a an engineering model (EM) but performed poorly when the subsequent flight build went to test, even though changes from EM to the flight model (FM) were thought to be minor. In addition, the circuit employed in this particular converter was not the typical design and its designer was no longer with the CYGNSS team. The NASA project manager responsible for this work requested the NESC provide consultation to help assess the issue and adjust the FM unit performance such that it was equal to or better than the EM unit by the least disruptive means possible.

The NESC Electrical Power Technical Fellow supported this effort by providing the theoretical foundation for how the circuit should function, identified aspects of measured waveform data that was representative of abnormal circuit operation and worked with a team of specialists in identifying aspects of the revised circuit in the FM that caused the deviation from normal circuit operation. That occurred on the first troubleshooting day and the Southwest Research Institute (SWRI) was able to adjust FM performance to be like that of the EM. However, the team noted several aspects of the design that should have been improved to gain all the intended design benefit across its load range. In short, while the team was able to get the EM unit performance out of the FM unit, that still fell short of what the design should have been.

To remedy the problem, the NESC team recommended the following:

1. Replace the power stage freewheeling diode with a lower reverse recovery part (primary issue)
2. Ensure the Quasi-resonant Zero Current Switched Buck Converter employed is capable of normal soft switching operation across the entire range of loads in input voltages.
3. In order to achieve more ideal operation, and improve circulating energy and hence efficiency, it was necessary to:
    a. Defeat the SiC body diode of the Metal Oxide Semiconductor Field Effect Transistor (MOSFET) with fast switching SiC Schottky diodes in the conventional manner by using 2 external diodes. This would improve speed and losses, reduce circulating currents and make the waveforms more ideal and hence present a more efficient operation.
    b. The current drive voltage of 10-12V was too low for this SiC MOSFET. It should be increased to 18V or more. This will require that the protection zener at 15V also be changed.

In summary, reasons for the performance deficit (even with the EM) were low MOSFET low drive, bad body diode performance, high circulating energy and possibly loss of soft switching for some operating points. All of which were correctable with the recommendations above.

3. SMAP

The Soil Moisture Active Passive (SMAP) mission, launched on January 31, 2015, is a NASA orbiting observatory that measures the amount of water on Earth's top surface. SMAP's global maps of soil moisture help improve our understanding of how water, energy, and carbon fluxes maintain our climate and environment. The mission has both an active (radar) and passive (radiometer) payload. While the mission's radiometer has been working flawlessly, the mission's radar ceased operation after 3 months of collecting data due to a power supply failure. The NESC's expertise was sought for risk assessments of the Reflector Boom Assembly, as well as failure analysis of the radar transmitter anomaly. These are discussed in the following sections.

3.1 Reflector Boom Assembly (RBA) Risk Assessment

The NESC Mechanical Systems Technical Discipline Team performed an independent risk assessment for orbit deployment of the RBA based on the overall design (including deviations from heritage), analysis, and test program used to qualify this system for flight. Included with this evaluation were recommendations to reduce the risk level. The spacecraft was scheduled to launch later in 2014, so the assessment required a very quick turnaround.

The assessment team generated a listing of all the mechanical subassemblies contributing to the deployment of the RBA and these items were further decomposed into their constituent mechanical components. The team then catalogued the environments to which the components and assemblies would be exposed during the SMAP mission in a matrix. Using data provided by the SMAP team, the team then populated the matrix noting what tests were performed on each component or subassembly in each environment and whether the test was a development, qualification, or acceptance test. This matrix was then submitted back to the SMAP RBA team for concurrence with the accuracy and completeness of the information it contained. Once the test mapping was identified, the NESC assessment team qualitatively scored the residual risk remaining from the testing or from the testing gap. This scoring was assessed on a relative scale with respect to the overall risk of the SMAP RBA system. The NESC team's ADAMS experts reviewed key modeling practices and assumptions, which would affect the results of Monte Carlo and sensitivity studies intended to correlate the model to ground testing and demonstrate positive margin for deployment of the reflector.

The NESC team supported the SMAP Reflector Boom Assembly V&V Closure Plan Review at JPL. Upon conclusion of this review, the assessment team formulated a list of questions that the team determined would allow for a proper review and risk assessment for the deployment of the SMAP RBA. The team discussed its initial observations with the SMAP Project and submitted requests for information (RFI). The SMAP project responded to the assessment team's RFI over several weeks. After careful review of the reflector deployment test data and analysis of the assumptions inherent in the ADAMS model, the following findings were identified in the NESC assessment: 1) The web/mesh strain energy stored in the stowed reflector was the driving force for the bloom phase of the reflector deployment. 2) The effects of vibration, vacuum, temperature, and time on the stored strain energy were not well understood and the effect of stowed time was not included in the energy margin analysis (ADAMS). 3) Positive margins for the bloom phase of the reflector deployment were obtained from ADAMS using an energy margin approach based on ambient system level ground testing and Monte Carlo analysis using appropriate knockdown factors for friction and bloom force based on component level environmental testing. 4) ADAMS could not be used to predict bloom anomalies, i.e. snags, hang-ups, asynchronous blooms, etc. 5) Significant thermal gradients were predicted on-orbit at high beta angle by the thermal model prior to bloom deployment and were not ground tested.

The following NESC recommendations were identified and directed towards the SMAP project: 1) Simulate the dynamic behavior of an uneven distribution of bloom deployment force (circumferential) and the powered deployment resulting from an asynchronous bloom. 2) If correlation analysis of ADAMS Monte Carlo results showed a strong correlation between bloom force factor and under-bloom criteria, perform coupon testing on the compressed mesh in a sustained thermal vacuum environment to aid in determination of a knock-down factor to be applied to the deployment bloom force/energy accounting for the effects of vacuum, temperature and time. Note: Information received after the stakeholder out-brief indicated that there was not a strong correlation between bloom force factor and under-bloom criteria, thus this testing was not required. 3) Minimize thermal gradients during the bloom phase of deployment.

The RBA exhibited no anomalies during deployment.

3.2 Radar Transmitter Anomaly

After a nominal launch on 31 January 2015, and a commissioning phase extending through 19 April 2015, the Soil Moisture Active Passive (SMAP) mission entered the science phase and began routine operations. On 7 July 2015 at 2:16 p.m. Pacific Daylight Time (PDT) (21:16 Universal Time Coordinated [UTC]), after 2027 hours of operation, the SMAP radar suddenly stopped transmitting. The spacecraft bus, the six-meter diameter spinning antenna, and the radiometer science instrument continued to perform normally. Immediately upon detection of the radar fault, the SMAP Project formed a response team. Through 24 August 2015, the team worked to diagnose the anomaly, but was unable to fully isolate the fault. Several attempts to restart the radar instrument were unsuccessful. Without the radar measurements, the SMAP mission could not meet its success criteria or Level 1 threshold requirements. On 8 September 2015, the NASA Science Mission Directorate (SMD) appointed a Mishap Investigation Board (MIB) to investigate the SMAP radar anomaly gathering information; analyzing the facts; identifying the proximate causes, root causes, and contributing factors related to the radar failure; and recommending actions to prevent a similar mishap from occurring. The MIB requested the involvement of the NESC Electrical Power Tech Fellow and he provided circuit analysis, modeling, testing and brought in industry peer reviewers to the data reviews held by the MIB. NESC resources were provided to sponsor testing in order to more fully flesh out MIB failure theories.

The analysis and test activities concluded that only a failure in the primary side of the LVPS (e.g., boost board, electromagnetic interference [EMI] filter, etc.) could create all of the observed conditions following the mishap. Hardware testing and circuit simulation identified four failure scenarios in the LVPS primary side that met these conditions, however, the NESC proposed a short circuit of the downstream forward converter. The SMAP Project made multiple attempts to restart the transmitter without success. The NESC/MIB joint team proposed it could not be restarted because damage in the primary subsystem propagated to other circuits, most likely to the EMI filter where current limiting resistors forced into circuit but the initial failure where subsequently damaged. Many lessons learned were derived from this activity including observations on the control and flight use of reworked PCBs, parts stress in designs, and fidelity of engineering units vs flight on the ways disparity here can blind the development team to performance. In addition, a trend was identified in this anomaly relating to accumulation of incremental risk in a manner not readily recognizable by the project and this was communicated to all NASA projects through the Engineering Management Board.

4. Deep Space Climate Observatory

The Deep Space Climate Observatory (DSCOVR) is a multi-agency (NASA, NOAA, Air Force) operational asset that performs space weather observations, by monitoring changes in the solar wind, and provides space weather alerts and forecasts for geomagnetic storms that could disrupt power grids, satellites, telecommunications, aviation, and GPS. DSCOVR was launched on February 11, 2015 and was placed at Sun-Earth's Lagrange Point L1.

Starting in June 2015, DSCOVR resets occurred with an average frequency of once per month. Once a reset occurs, the spacecraft enters safehold mode and observations stop until the ground operations team returns the spacecraft to an operational mode. A NASA/NOAA Failure Review Board (FRB) was established to investigate the reset anomalies. The team was unable to determine root cause. In November 2016, the NESC was contacted for an independent assessment.

The assessment focused on analysis of flight software diagnostic event messages and telemetry from the DSCOVR spacecraft computer at the time of anomalous reset events. During a reset event, telemetry is lost for a specific duration that is dependent on the reset mechanism (i.e. processor exception, processor watchdog, power cycle). It was discovered that diagnostic event messages and telemetry exhibited a signature that was inconsistent with the expected behavior of the spacecraft computer reset architecture. An "upset" in the DSCOVR hardware was initiating unexpected resets outside of the normal expected reset architecture and "fooling" the flight software diagnostic reporting. The team identified the flight computer PCI bus as a potential source of these hardware upsets. A review of the design uncovered insufficient data-to-clock hold time margin on the PCI bus that could disrupt internal communications and cause a computer reset with the signature observed. The NESC recommended a simple, yet elegant, enhanced diagnostic procedure to enhance on-board software diagnostics.

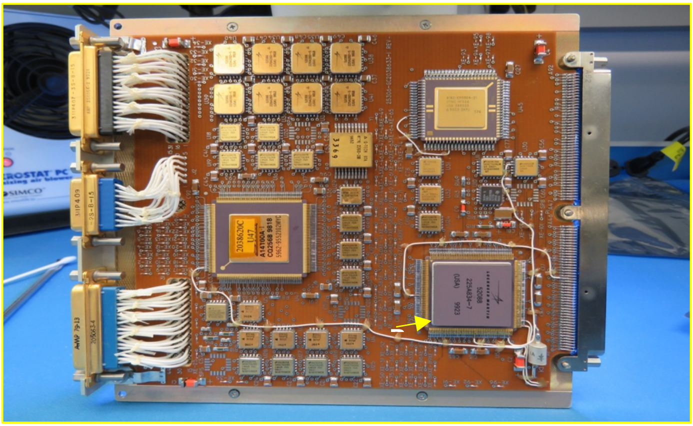

Figure 3. DSCOVR Flight Computer Processor Board

5. Joint Polar Satellite System

The Joint Polar Satellite System (JPSS) is the latest generation of U.S. polar orbiting, non-geosynchronous environmental satellites. JPSS is a collaborative program between the National Oceanic and Atmospheric Administration (NOAA) and NASA. Satellites in the global JPSS constellation gather global measurements of atmospheric, terrestrial, and oceanic conditions. Data from JPSS enable severe weather forecasting days in advance, as well as help assess environmental hazards such as droughts, forest fires, and poor air quality.

NESC's expertise was sought to evaluate Micrometeoroid and Orbital Debris environment (MMOD) models used by JPSS-1 and recommend strategies to reduce MMOD risk. NASA's orbital debris environment model (ORDEM3.0) had just undergone a revision, and MMOD risk assessments performed using the newest version were resulting in much higher calculated MMOD risk than when using the older model. The NESC compared the MMOD environment models to other models developed by the European Space Agency and private industry in order to understand the differences between them (Figure 4). The NESC team identified recommendations to improve the NASA model but overall felt that, compared to the other models evaluated, the NASA model was the best option for MMOD risk assessments associated with JPSS-1. These results were relevant beyond JPSS and SMD because this orbital debris model is used throughout NASA and the space industry in general.

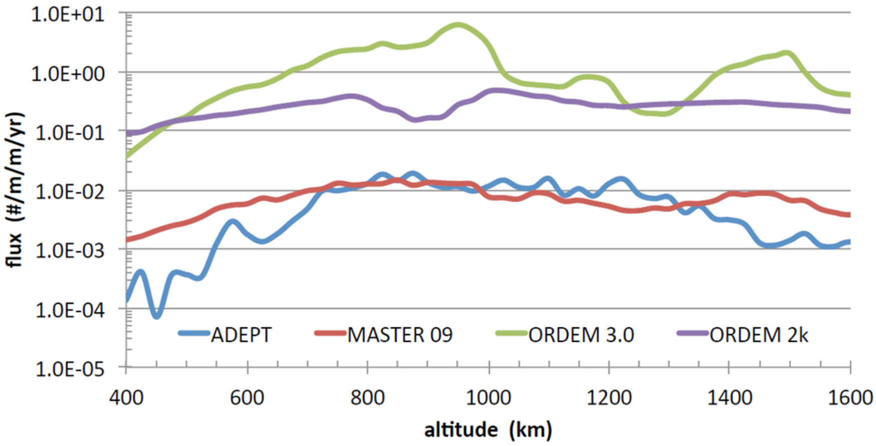

Figure 4. Comparison of four different orbital debris models for 1 mm sized particle flux as a function of altitude

The NESC also helped JPSS-1 understand other elements of MMOD risk besides the environment models to reduce both the predicted risk and the actual risk. For example, ballistic limit equations (BLEs) define how an MMOD particle will interact with an impacted surface to result in a failure. There are different types of BLEs, and the NESC recommended a type of BLE that was more appropriate to the JPSS-1 than what was previously used, which also resulted in lower assessed risk. In addition, the NESC performed simulations of MMOD impact on avionics boxes, showing that the failure criteria JPSS-1 was using may have been too conservative. This along with conservatism identified in the pressure vessel failure criteria were resulting in unnecessarily elevated assessed MMOD risk. Actual MMOD risk was also addressed with design recommendations for wire harness shielding based on MMOD impact modeling performed by the NESC.

The results of this assessment are presented in a NASA Technical Memorandum[2].

6. ICESAT-II

The Ice, Cloud, and Land Elevation Satellite-2 or ICESat-II is a satellite mission for measuring ice sheet elevation and sea ice thickness, as well as land topography and vegetation canopy using laser altimetry. It was launched on September 15, 2018 carrying a photon-counting laser altimeter payload called Advanced Topographic Laser Altimeter System (ATLAS).

ATLAS, the sole instrument on the mission, carries two separate and redundant lasers. The lasers emit visible, green laser pulses at a wavelength of 532 nm at a rate of 10 kHz. A key component that enables the pulsing is the Q-switch, each made up of two rubidium titanyl phosphate (RTP) crystals bonded to a mounting fixture. The Q-switch planar dimensions are roughly 3.8 cm long by 1.9 cm high. During development, several Q-switch assemblies experienced debonding of crystals, and concerns arose with the bond reliability of the flight laser Q-switch crystal to its mount. Of particular concern were how well the material properties of the crystal and the adhesives were understood, as well as the loads being imparted on the bondline by how the crystal wires were routed.

The ATLAS project requested the NESC's technical support to review the results and findings from a project failure review board (FRB) and specifically sought a technical position on the risk of flying the Q-switch designs as-is. The FRB developed a test program to determine material properties and loads, both of which were incorporated into a Finite Element Analysis. In parallel, shear and cleavage tests of samples were used to determine strength allowables. Both elements were then used to make a risk assessment. The NESC team made significant contributions in understanding of the statistical significance of the available test data, and in fact, did not concur with the FRB approach in estimating the bondline strength performance margin. This stemmed from the lack of appropriate statistical bonds for analysis assumptions, resulting on what was believed an unreliable indicator of bondline structural integrity and an inability to quantify ATLAS Q-switch margins. The NESC's opinion was that they couldn't substantiate a "low" risk for the Q-switch bondline performance. Instead they suggested that instrument performance and environmental testing was more appropriate data for making the decision to retain the switches already installed on the lasers. The instrument redundancy (i.e., having two lasers on-board) and requiring only one functional unit for mission success contributed to mitigate the risk. Those risks also had to be balanced with the potential implications related to Q- switch removal and replacement. While the NESC disagreed with the FRB findings, its evaluation and position were invaluable in helping the project evaluate the risk and arrive at its decision to not change the switches. The NESC involvement was particularly value-added because this was not a clear-cut technical situation with abundant and clear data. Those situations that require expert judgement are not always easy for a project to justify and having a neutral party like the NESC provide perspective is significant.

A completely different assessment the NESC also did for ATLAS related to the system's Beam Steering Mechanism (BSM). In this case there wasn't an existing problem, but the ATLAS team sought an independent perspective on the development of the BSM. The ATLAS instrument directs six laser beams to the ground in a 2 x 3 configuration. Each of those beams have to be aligned with the receiver back on-orbit such that all the returned energy is captured, and therefore making an accurate altimetry measurement. The transmitted beams are 27 microradians and the receiver field-of-view is only 66 microradians requiring very high precision out of the BSM, which was an in-house NASA design after the original contracted system did not meet requirements. Due to the criticality of the BSM the ATLAS project engineering team requested an independent assessment from the NESC of the requirement's viability, alternative approaches associated risks, and alternative design solutions as plan-B candidates compatible with the available resources and schedule. To address the ATLAS request, the NESC team, 1) performed a system-level study of the ICESat-II/ATLAS architecture to assess the technical issues/problems that led to the introduction of a BSM in the design and assessed the calibration scheme, 2) assessed the planned BSM implementation, and 3) identified, studied, and analyzed optional architectures and/or mechanisms that used alternate approaches to resolve the issue/problem and/or that simplify the calibration scheme. The NESC team concluded that the planned design, based on voice coil actuators, was a reasonable approach for the ICESat-II/ATLAS application. Voice coil actuators were proven and flight qualified actuators of its kind had been used in other spacecraft. Furthermore, the NESC concluded alternate actuator options would require a major change in the architecture (electrical, mechanical, optical, or thermal) and would be expected to have a significant impact on cost and schedule. The NESC team also pointed out a number of risk areas and suggested mitigating strategies. This allowed the ATLAS team to confidently proceed with their BSM design, which was indeed completed to meet all system expectations. Again, the role of the NESC in this case was one of a trusted independent party with valuable perspective to help projects not only to solve problems once they happen, but as in this example provide a sound basis for the project plans.

7. NASA-ISRO Synthetic Aperture Radar

The NASA-ISRO Synthetic Aperture Radar (NISAR) mission is a joint collaboration between US and India with a planned launch in 2022 into a near-polar orbit. NISAR will observe Earth's land and ice-covered surfaces globally with 12-day regularity, collecting radar data in both L-band and S-band to measure changes in the Earth's surface less than a centimeter across.

During NISAR's design phase, the Project had been unable to meet the MMOD risk requirements due to components that are exposed to the MMOD environment, primarily cables located on the ram side (i.e., side facing the orbital direction of motion) of the spacecraft. The NISAR Project requested the NESC's help in reviewing NISAR's overall MMOD risk assessment, assessing the risk to vulnerable cables on the spacecraft, and developing a risk mitigation strategy.

The NESC performed an independent review of NISAR's overall risk assessment. NESC team members from JSC's Hypervelocity Impact Technology Group evaluated the assumptions, methodologies, and tools used by the NISAR Project in assessing the overall MMOD risk and found them to be appropriately applied. The NESC results were also consistent with NISAR's in that the assessed MMOD risk exceeded the requirements. To address this, the NESC team performed Smoothed-Particle Hydrodynamics (SPH) modeling code to simulate MMOD impacts on the exposed cables to derive the critical particle sizes that would cause failure to the cables.

Once these sizes were determined, the team was able to recommend shielding strategies, also simulated by the NESC team, to reduce the MMOD risk to acceptable levels.

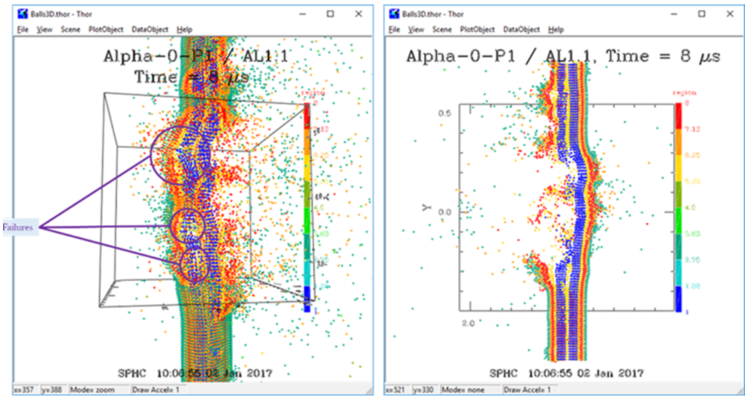

Figure 5. SPH Model of a cable experiencing an MMOD impact

8. SUMMARY AND LOOKING TO THE FUTURE

We have highlighted a few examples of technical challenges encountered from design to operation of NASA and NOAA Earth science missions in which the NESC stepped in to resolve technical issues that ultimately led to mission success and safety. The technical resolutions spanned a broad array of technical disciplines including space lidars and radars, electronics, reaction wheels as well as modeling and risk assessment of MMOD impact to NASA and NOAA missions. Additionally, NESC was involved in some failure review boards (FRB) to aid in identifying root or probable cause failures. In many cases, the NESC work led to capturing lessons learned and publication of NASA technical bulletins or memoranda that the Agency continues to benefit from by avoiding similar mistakes on future missions.

NASA has a diverse Earth science portfolio worth approximately $1.8 billions in FY20 which supports a robust Venture Class Program and upcoming launches for Landsat-9, NISAR, SWOT, as well as concept formulation for an array of observatories as recommended by the National Academies Decadal Survey. NESC's technical resources and expertise will continue to be a great asset in ensuring mission success and safety of the entire NASA science mission portfolio. Other current ongoing support of NASA or NOAA Earth science mission portfolio by NESC include work for the Ocean Color Instrument (OCI) on PACE, GOES-R, and future mission architectures.

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[2] Squire et. al., NASA Technical Memorandum 2015-218780, Joint Polar Satellite System (JPSS) Micrometeoroid and Orbital Debris (MMOD) Assessment