SmallSat Reliability Technology Interchange Meeting (TIM) Summary

Miquel A Moe
NASA Goddard Space Flight Center (GSFC)

Erica A Sullivan
Los Alamos National Laboratory (LANL) LA-UR-17-23901

Introduction

SmallSats are widely recognized by industry as small satellites with masses not exceeding 200 kg. They offer benefits that make them attractive to many mission profiles. When compared to traditional satellite missions these benefits can include shorter development times, lower costs, opportunities to ride share, and scalable mission assurance activities. As the SmallSat market continues to grow there is increased concern regarding reliability. Currently there aren't any industry standards or guidelines for SmallSat reliability activities across different risk classes. The lack of standards and recommendations is a significant factor contributing to inconsistent SmallSat mission success and higher failure rates when compared to traditional larger satellites. SmallSats have different sub classifications, one of which is CubeSat. SmallSats could be developed using CubeSat components and subsystems but will not have the CubeSat form factor. Both CubeSats and SmallSats could then be used where their attributes enable or enhance mission objectives or provide other meaningful benefits.

In an effort to address the CubeSat-SmallSat reliability problem, representatives from the NASA Goddard Space Flight Center (GSFC), NASA Jet Propulsion Laboratory (JPL), Los Alamos National Laboratory (LANL), MIT Lincoln Laboratory, and Aerospace Corporation were tasked by the Chief Technologist, Engineering Directorate at NASA GSFC, and the Chief Technologist, Engineering and Science Directorate at NASA JPL to form a subcommittee dedicated to achieving the following:

Subcommittee Charter: Recommend approaches to achieve reliability/risk tolerance associated with each mission risk class. Define and leverage novel component, subsystem, spacecraft, and mission-level risk mitigation strategies that maintain, to the extent practical, cost efficiencies associated with small satellite missions. Consider constraints associated with supply chain elements, as appropriate.

The subcommittee worked on recommendations to address the aforementioned charter in preparation for a Technology Interchange Meeting (TIM). The TIM was held at The California Institute of Technology on February 14th and 15th of 2017. The objective of the TIM was to reach agreement on a common language to help set expectations for CubeSat-SmallSat missions and expectations on the level of mission assurance for each classification. During the TIM, the

subcommittee presented its findings and recommendations to date, and solicited feedback and recommendations from attendees through splinter sessions and focused topic presentations. The TIM attendees included representatives from civil, DoD, academic, and commercial CubeSat providers and stakeholders.

This paper is intended to communicate the initial subcommittee findings and conclusions of the TIM.

Subcommittee Findings

CubeSats emerged in the late 1990s as training tools for university students; they were inexpensive packages that could be used to teach students to build space hardware, while not endangering large mission-critical satellites. However, as budgets for long-term space research and missions have tightened over the last few decades, space system users have started incorporating CubeSats into mission systems. Both governmental and commercial space programs are seeking to leverage the lower cost and faster development times of CubeSats, while still performing critical missions in space. This presents a challenge to maintain these benefits while also applying an appropriate level of mission assurance activities; this requires a holistic development approach.

The first task for the subcommittee was to define risk levels and create a standard SmallSat/CubeSat risk classification nomenclature. The resulting nomenclature is similar to the NASA risk process defined in NASA's Risk Classification Guidelines document, NPR 8705.4, but scaled for CubeSats. This nomenclature consisted of 4 risk categories: Alpha, Beta, Gamma and Delta.

Alpha denotes the lowest risk posture (highest reliability requirement) class where the most mission assurance activities would be performed, and Delta is the highest risk posture class (lowest reliability requirement) with the least amount of mission assurance activities. The subcommittee emphasized the need for a holistic approach and recommended that all CubeSat systems go through a systems-level review with the cognizant engineers, scientists, and stakeholders early in the system life cycle to determine the mission assurance requirements. The intent of this review would be to allow cognizant engineers and stakeholders to tailor requirements as they make sense for the given mission application, instead of performing activities to check boxes that don't add value to the program. An example of this would be if a CubeSat vendor decided to use purely commercial Electrical, Electronic, and Electromechanical (EEE) parts in a non-critical application, and automotive grade parts in a critical application.

After creating and agreeing on the risk classification nomenclature, the subcommittee began addressing how a stakeholder might determine which category best fits their mission or subsystem. The subcommittee determined that orbit, environment, mission length, criticality (i.e. national security, science mission, technology demonstration), and configuration (single satellite or constellation) should all be taken into account by the stakeholder determining the appropriate risk classification. After establishing the guidelines that should be used to determine the appropriate risk classification of the CubeSat, the subcommittee then began focusing on the appropriate level of activities for different mission assurance requirements within the different

classifications. The mission assurance categories evaluated by the subcommittee included the following:

- ***Design Activities*** (CAD models, configuration control, etc.)
- ***Analysis Activities*** (Thermal Model, Worst Case Analysis (WCA), Failure Modes and Effects Analysis (FMEA), etc.)
- ***Reviews*** (PER, SRR, CDR, etc.)
- ***Documentation*** (Program Plans, Test Plans/Procedures, Requirements, etc.)
- ***Tests*** (Vibration, Thermal-Vacuum, Thermal Cycling, etc.)
- ***Build and Sparing Policy*** (Engineering Test Units (ETU), Flight Spares, Qualification Unit, Flight Spares, etc.)
- ***Safety***
- ***EEE Parts and Radiation Assurance***
- ***Materials and Processes Assurance***
- ***Software Assurance***
- ***Printed Circuit Board (PCB) Assurance***
- ***Quality and Workmanship Practices***

The subcommittee proposed activities required from the disciplines listed above, for each risk posture category, Alpha through Delta. This effort is still in process. The draft recommendations were formulated with the understanding that they were subject to change per recommendations made at the TIM.

TIM Findings

The TIM was structured in a way to promote thinking beyond proven and traditional methodologies. This committee is tasked with identifying transformational solutions enabling the traditionally risk-adverse space community to adopt a new paradigm of space hardware engineering. The two-day event featured presentations of CubeSat science and operational mission drivers from various organizations, select industry topic presentations including lessons learned, and presentations from the subcommittee regarding its findings and recommendations. The mission assurance discussions were split into two categories. These categories were mission/system level assurance approaches and subsystem/component level assurance approaches. There were also presentations and discussions on future investments and knowledge sharing/collaboration.

The TIM feedback on the subcommittee's proposed risk classification system was that it was not very useful. Many of the TIM attendees stated that the system was too similar to NASA's traditional classification system and could therefore lead to significant constraints and burdens on a CubeSat mission. Many of the TIM attendees felt that by classifying a mission as Alpha through Delta, it eliminated the flexibility needed to tailor mission assurance activities for specific subsystems and components. There was also disagreement regarding the number of bins needed for a CubeSat, i.e. 3 classes vs 4. Ultimately, there were two major recommendations regarding the subcommittee's recommended risk classification system. The first recommendation was that a confidence based approach is preferred over a risk based approach. Instead of

characterizing risk, a CubeSat mission should instead perform some level of assurance activities to achieve a threshold of confidence acceptable for their mission. Secondly, it was stated that a "menu style" approach is preferable when determining mission assurance activities for a CubeSat. Using a menu style approach, a CubeSat mission would apply a holistic approach to mission assurance and tailor its requirements based on trades at the mission or system level. With this model, a CubeSat mission may decide to perform high confidence mission assurance activities in certain areas and medium or low confidence activities in other areas, based on which components of the CubeSat are required absolutely to meet performance requirements on orbit. Effectively, the mission would select its activities from a menu and a determination of confidence level would be made based on the activities performed and other contributing factors.

The mission and system level assurance activities discussion included two splinter topic sessions. TIM attendees were split into two groups, each group attended one of the splinter topic sessions and there was a joint discussion at the end. The first splinter topic discussion was titled "*Applying a holistic approach to SmallSat/CubeSat mission assurance that combines systems and component level thinking*". This discussion focused on changing engineering mindsets when working with CubeSats versus traditional large satellites. All participants agreed that when a mission is comprised of multiple CubeSats, as opposed to a single high-reliability asset, the evaluation of success changes—the question becomes whether the CubeSat constellation achieves its mission, not whether all parts of the system performed flawlessly. Risk calculations for CubeSats systems need to take into account statistical reliability (i.e. some or most systems work well enough to achieve the mission, even though there are failures on some of the satellites) to determine how much risk a mission can tolerate, and then design to that risk. Therefore, the engineering development focuses on system resiliency to issues, and designing around failure modes, rather than trying to eliminate failures altogether.

Success is best achieved when considering the processes to determining reliability of a system. System-level testing processes include fully testing a system to failure, testing for to characterize failure modes of critical subsystems, and methodically removing testing of components that already have flight heritage. The participants suggested that in order to push down risk and component-level test costs, CubeSat developers should fly new technologies on missions where that technology is not critical, so that some flight data can be collected. This enables cyclical technology insertion by testing components and determining their failures modes, when those components are not critical to mission success.

A representative from Planet at this meeting described Planet's success in embracing the "fly-fix-fly" approach to technology insertion. His conclusion was that on-orbit testing provided the best results, and that despite the fact that on-orbit failures can be difficult to accept, "if you just keep going, eventually you get there".

Finally, all participants agreed that even in the fast-moving CubeSat market, it is essential to take a break between build cycles to capture lessons learned and incorporate those lessons in the next design phase.

The second splinter topic discussion was titled "*For each classification level, what is the appropriate level of testing (i.e. TVAC, Vibration, etc.)? What is the appropriate build and sparing policy?*". A summary of this splinter session is not available at the time.

Day 2 of the TIM focused on component and subsystem level assurance activities and included two splinter topic sessions on the subject. The first splinter topic discussion was titled "*At what point do changes and iterations made by a subcomponent vendor require a re-qualification of that subcomponent? What types of data should be collected from SmallSat/CubeSat subcomponent vendors to perform a Bayesian assessment?*". During this splinter topic, participants discussed the need for a standard list of questions that facilitate discussion and transparency regarding a vendor product that has changed. The threshold for requalification could vary depending on the design, heritage, pedigree, and other factors. Therefore, it is important to know what changes have been made since the last qualification, what impacts those changes have on the system, and whether a vendor has confidence that a requalification should be performed. TIM attendees discussed testing at the board level instead of the part level when a requalification is performed and the possibility of performing analyses in lieu of requalification testing. When quantifying risks associated with design changes the TIM attendees largely recommended a 5X5 risk scale that is appropriate for SmallSats. It was also recommended to focus on qualitative data instead of quantitative data, and factor in heritage and pedigree.

The second splinter topic discussion on components titled "*What is the proper piece part pedigree (i.e. mil spec, automotive, commercial) for the different SmallSat/CubeSat classes?*". The consensus amongst the participants was that commercial grade EEE parts are appropriate for CubeSat missions with some caveats. When using commercial EEE parts, care should be taken to ensure good thermal, mechanical, and electrical design to reduce parts stress, as well as robust board and system level testing to flesh out infant mortality issues. Limiting the thermal excursions experienced by the EEE part can significantly increase its operating life time. Selecting parts with at least the industrial grade temperature range, having a thermal engineer involved early in the process, and taking other thermal stress reducing measures were discussed. Similar discussion took place with regard to mechanical and electrical designs. It was recommended that missions involve a mechanical engineer early in the process, and electrically derate part specifications where possible. Radiation effects can be a threat to mission success and must be seriously considered for a CubeSat mission. In some cases, part radiation testing may be necessary but there was a significant emphasis placed on radiation tolerance through design. Many TIM attendees stated that in cases where they feel higher reliability is needed for a particular part they consider using automotive grade components, although radiation effects still must be considered separately.

The TIM concluded with discussions about data sharing, collaboration opportunities, and future investments.

There was universal consensus that a parts database containing radiation test results and other failure and anomaly information would be very useful to the CubeSat community. AFRL has nearly completed development of its Space Parts on Orbit Now (SPOON) database. The SPOON

database contains reliability information on previously-procured CubeSat subsystems. The SPOON database is not yet available for all users. While everyone agreed that database and information sharing would be useful, there are also some obstacles to overcome that must be addressed to reach this goal. It was agreed that this type of data sharing will require government leadership and moderation. Access control, source data anonymity, and data format standardization are examples of some of the challenges that must be worked through to establish the type of data sharing desired by the industry.

Much of the future investment discussion was about investing in data sharing. There were also discussions about the government sponsoring radiation testing of selected CubeSat EEE parts and making the results available to the industry. An intermediate solution discussion centered on investing in the creation of a stack exchange where questions about CubeSat reliability can be asked and answered by subject matter experts. Software is another area requiring further discussion and future investment. Government-Off-the-Shelf (GOTS) Software, and NASA and DoD software licensing were some of the things discussed by the TIM attendees. It was agreed that software needs more attention and should be discussed in greater detail during another event. Some of the other areas requiring future investments that were agreed to by the TIM participants included “common radios”, augmenting CubeSat communication opportunities (i.e. Iridium and Globalstar), developing methods for easier assembly and disassembly of CubeSats, and working with launch services to develop better dispensers.

Conclusion and Path Forward

In conclusion, the TIM was a success in that it created an atmosphere of free and innovative idea exchange amongst its attendees. The subcommittee has taken all feedback into consideration and will continue to meet and work on a confidence based approach for the different mission assurance disciplines needed to address CubeSat reliability. These recommendations will be documented in a paper that could ultimately be used as the frame work for an industry CubeSat standard. The AIAA/USU Conference on Small Satellites has accepted the subcommittee abstract titled “*Increasing Small Satellite Reliability- A Public-Private Initiative”.* The subcommittee will work collectively to complete the paper and prepare for the conference, which occurs in August 2017. A 2nd Small Sat/CubeSat TIM is tentatively scheduled for October 2017 at NASA Headquarters. In parallel to the subcommittee’s efforts, collaboration opportunities should be thoroughly explored for all areas where it is advantageous to the community (e.g. radiation and EEE parts database, failure and anomaly database, etc.).

CubeSats present excellent opportunities for many different mission profiles and applications. If the public and private sectors continue to work collectively on the development of appropriate mission assurance activities, the end result will be very beneficial to all SmallSat users.

Upcoming Events

- **AIAA/USU Small Satellite Conference August 5th – 10th, 2017**
- **2nd SmallSat/CubeSat TIM October 11th and 12th, 2017**

Appendix A TIM Attendees

- ***NASA Headquarters***
- ***NASA/ JPL***
- ***JPL/CalTech***
- ***NASA GSFC***
- ***Tyvak Nano-Satellite Systems, Inc.***
- ***The Aerospace Corporation***
- ***Small Spacecraft Systems Virtual Institute (S3V1)***
- ***Air Force Research Laboratory (AFRL)***
- ***VACCO Industries***
- ***MOOG Inc.***
- ***HQ USSOCOM/ SOF AT&L***
- ***Blue Canyon Technologies***
- ***NOAA/NESDIS/ROPPD***
- ***Maryland Aerospace Inc.***
- ***LANL***
- ***The University of Michigan***
- ***SSC Pacific***
- ***Phase Four Inc.***
- ***Pericle Communications Company***
- ***Innoflight Inc.***
- ***Vulcan Wireless***
- ***MIT Lincoln Laboratory***
- ***Kubos***
- ***Planet Labs Inc.***
- ***Accion Systems***
- ***Space Dynamics Laboratory***
- ***Spaceflight Industries***
- ***NASA Ames Research Center***
- ***GeoOptics Inc.***
- ***Surrey Satellite Technology LLC***