18 December 2017

Small Satellite Reliability Initiative
Technical Interchange Meeting 2
11-12 October 2017, NASA Headquarters

Meeting Notes

Background

The potential for SmallSats to enable or enhance mission objectives or to provide other meaningful benefits is attracting broad interagency interest. The performance of these platforms however often precludes infusing them and their systems into missions where significant risk of failure is unacceptable. This, and the inability to quantify SmallSat mission risk or mission confidence are barriers to infusion.

The second Small Satellite Reliability Technical Interchange Meeting (TIM-2), convened October 11-12 at NASA Headquarters targeted this challenge. Attendees included invited representatives from various government agencies, universities, and industry. The meeting hosted sessions on; Lessons Learned from various spaceflight programs, Model Based Systems Engineering (MBSE) and Model Based Mission Assurance (MBMA), Knowledge Sharing, and Best Practices and Design/Development Guidelines.
The objective was to continue progress towards progress towards defining implementable approaches that will lower barriers, as directed in the initiative charter:

"Define implementable and broadly accepted approaches to achieve reliability and acceptable risk postures associated with several SmallSat mission risk classes—from "do no harm" missions, to missions whose failure would result in loss or delay of key national objectives. These approaches will maintain, to the extent practical, cost efficiencies associated with small satellite missions and consider supply chain elements constraints, as appropriate.

"Address this challenge from two architectural scopes—the mission- and system-level, and the component- and subsystem-level. The mission- and system-level scope targets assessment approaches that are efficient and effective, and mitigation strategies that facilitate resiliency to mission or system anomalies while the component- and subsystem-level scope addresses the challenge at lower architectural levels."

The effort is aligned with Thomas Zurbuchen's (NASA Science Mission Directorate Associate Administrator) challenge to NASA to lean forward, think outside the box, and do more with fewer resources. To this end, Initiative leadership encouraged attendees to consider "thinking different," to be prepared to question and intelligently deviate from heritage systems and processes, and to be eager to challenge culture and catalyze change.

Notes from TIM-2 sessions are as follows.

Lessons Learned Session

Ryan Miller of University of Michigan: MDA QB50 Lessons Learned
(See https://www.qb50.eu for QB50 background information.)

Ryan was Chief Engineer for QB50, an international network of CubeSats for multi-point, in-situ measurements in the lower thermosphere and for re-entry research. The CubeSats he and his team developed are part of a 36-satellite constellation led by the Von Karman Institute in the European Union.

The two CubeSats were to be student projects—one at the University of Michigan, and the other at the University of Puerto Rico, but the students got behind schedule. The work was transferred to the Space Physics Research Laboratory (SPRL) at the University of Michigan to remediate this challenge.

Ryan and his team faced a significant challenge: design and build two CubeSats in five months. The team would be taking on elements they had not previously done, including but not limited to the radio link, solar panels, attitude control, and satellite integration.

A small group of professionals and a few full-time students comprised the SPRL team. They decided it would take too long to learn and understand the student design, so they started from the beginning.

Ryan associated the following attributes with the project's success:
- The development team was small and experienced;
- Administrative burdens were streamlined;
- The team relied on our engineering expertise since there was no time for reviews;
- They did not conduct time-consuming analyses and reports;
- Engineers served in a primary role. They provided oversight to students who supported the project;
- The satellites were designed for easy testing and assembly.

The team completed work by September 2016 in time for October NanoRacks deployer integration. The satellites were launched to the International Space Station (ISS) in April 2017 and deployed from ISS May 2017. They have not experienced reboots as of mid-October 2017. Drag panels were deployed that de-tumbled the satellites within about two weeks. Downlink is good, but uplink is not reliable.

The design team stayed away from ball grid (BGA) packages, avoided ribbon cables, and used normal derating guides. The team used many components from a Digi-Key catalog as there was not enough funding or time to purchase space-grade components. The design incorporated selective redundancy, and power control to enable independent subsystem control.

The team used a central processor unit they had experience with—the ColdFire— embedding an IP (intellectual property) core in a Microsemi Pro ASIC radiation tolerant field programmable gate array (FPGA). JPL performed radiation tests on this component. It has flight heritage despite not being a device on the qualified parts list (QPL). They also used Everspin Magneto-Resistive MRAM memory devices; MRAMs are inherently tolerate to radiation effects. The bus uses a 1W transmitter and a tape measure antenna.

The team fabricated solar panels. They utilized multi-layer double-sided adhesive tapes for bonding with vacuum pressure, and developed tab cutting and recycling methods. They did full 3D modeling for the mechanical design. They used magnetic-torquers and drag panels as they did not have enough power for reaction wheels.

The team tested the systems thoroughly and incorporated fault handling into the design. Multilayer double-sided tape was used to attach solar cells to the panel substrate.

The workload was 6 FTE full time for five months with additional part-time support for specific subsystems. Since students can only devote 10 to 15% of their time to such efforts, heavy reliance on a student workforce would have unacceptably stretched to project duration to 2 to 3 years.

Some of the QB50 lessons learned Ryan conveyed are as follows-

- Satellite reliability is achievable. It requires careful component selection, fault, handling procedures, well thought-out designs, and testing.
- The backplane approach the design team implemented was very successful. It facilitated ease of assembly and test, allowing individual board testing with an extender card. It also largely eliminated cabling.
- The team developed a burn mechanism for deployables that consists of a thermal knife and nichrome wire heating elements which doubled as hold-downs. It was an improvement over the widely used fishing line/resistor method.
- The ColdFire IP (Intellectual property) core processor was critical and very successfully implemented.
- The team found their implementation of point-to-point interfaces very successful. They also found that a high level of integration saved additional board designs.
- The design team required full integration and test of third party modules.
- Careful attention must be given to battery selection. Testing is time consuming, but essential.

Chris Ruf, University of Michigan: Lessons Learned from CYGNSS (Cyclone Global Navigation Satellite System)
(See https://www.nasa.gov/cygnss/overview and http://clasp-research.engin.umich.edu/missions/cygnss/ for CYGNSS background information.)

A detailed CYGNSS 1-day lessons learned workshop will be convened at NASA Langley Research Center in March 2018. An abbreviated meeting will be convened at NASA HQ. Greg Stover/Stuart Cook are leading this activity. (Look for a notice from Mike Johnson as he asked for details to disseminate.)

CYGNSS measures ocean surface wind speed (not direction) by measuring GPS signals scattered from ocean waves. It has high revisit rate with its 35° inclination circular orbit, and uses a 4-channel modified GPS receiver. The use of a very low frequency enables rain penetration and measurement of a hurricane inner core. The system cannot make vorticity patterns.

CYGNSS can measure scattering off land and is very sensitive to soil moisture (like the SMAP mission), but has a higher revisit rate. It can also measure flooding. The team plans to augment the science team in order to use land data.

The science payload is still being calibrated. The team would have liked additional pre-launch testing, as is the case with many larger spacecraft-based missions, but they did not have time or funding for ground calibration. They had two months of data and calibrations before a public data release.

The team set a lower bar for requirements and a higher bar for goals. The design life is two years with a goal of four years. Funding was $100M for the spacecraft and the science team, and $46M for launch. They contracted Kennedy Space Center to handle launch. The team desires to increase automation as much of the process is still manual. The process is improving, with a goal of near real-time operations almost achieved.

To increase reliability, the team built different engineering models in parallel before they built the first flight model (FM) to make sure design was robust. They then built one FM and tested it thoroughly before building the remaining seven. The final builds proceeded much more quickly than the first

Several calibration algorithm corrections were needed or are still in development for the science instruments. Observed inadequacies of the Day 1 algorithms resulted primarily from limitations in the pre-launch testing, modeling and simulations. (Such post-launch corrections are not uncommon with larger missions.)

Randy Rose, Southwest Research Institute: More CYGNSS Lessons Learned
CYGNSS is a Class D mission comprised of eight 25kg spacecraft that started as CubeSats, but evolved to SmallSats given the volume required for the payload and spacecraft systems. They were launched on a Pegasus rocket.

The spacecraft are single string but implement some functional redundancy. The mission architecture also provides redundancy. The design eliminated or mitigated potential systemic issues that could compromise the intent to achieve redundancy via multiple spacecraft.

The spacecraft incorporate first-generation CubeSat-class components. They were integrated with more reliable spacecraft control and software. Upsets from the South Atlantic anomaly are observed. Single Event Upsets (SEUs) were predicted, but could not be fully identified in analysis for cost reasons.

The spacecraft are single string but implement some functional redundancy. Redundancy is also implemented at the constellation level. The design eliminated or mitigated potential systemic issues that could compromise the intent to achieve mission-level redundancy. The team kept fault mitigation simple and robust. They implemented a thorough EEE parts program and carried robust power margins.

Key lessons learned are to use good components and talented engineers.

The recurring spacecraft cost is $5M-$6M.

Chris Hargrove, Arizona State, Lunar CubeSat
(See https://www.nasa.gov/feature/lunah-map-university-built-cubesat-to-map-water-ice-on-the-moon and http://lunahmap.asu.edu/ for LunaH-Map background information.)

The LunaH-Map mission was competitively selected from the first NASA Small Innovative Missions for Planetary Exploration (SIMPLEx) program competition. The spacecraft will occupy an elliptical orbit 10-15 km over the moon's south pole. The targeted mission duration is one year. Baseline science occurs over two months. This is a high-risk mission but will provide complimentary data to existing missions. AZ Space Technologies is responsible for spacecraft engineering, integration, and test of the 6U+ satellite. Full and part-time engineers comprise the team.

The mission will use a Tyvac deployer that is larger than 6U. Most of the components and some of the software are procured from eternal companies. The Command and Data Handling system was procured from Blue Canyon Technologies. Propulsion is provided by a Busek BIT—3 thruster. The development program includes build of an engineering development unit (EDU) instrument. The mission incorporates a miniature neutron spectrometer.

The team has and will conduct several reviews—System Readiness, Preliminary Design, and Critical Design—, an integration and test (I&T) workshop, and an I&T review. Board members include other NASA/JPL engineers working other SmallSat missions. They will not conduction traditional gate reviews. Launch is scheduled for December 2019. The budget $5.4M, not including launch.

There are potential issues with heritage boards as parts can be (and are) changed without notification to end users. An example was stated where a company changed adhesives used for UV sensitive optics without test or informing the buyer. Such practices can (and did) create challenges. The six-month to three-year technology refresh cycle for commercial components can raise additional issues.

Model-Based Approaches to Mission Confidence Session

Model-based (MB) approaches can aid design decisions through the product lifecycle. The fidelity of a model can be tailored to fit targeted objectives—low fidelity models might support architecture studies whereas high-fidelity models might support quantitative analyses at the expense of added complexity and longer run times.

Whereas the presentations largely addressed automotive systems, the approach can be agnostic of the application. Hence the relevance of the discussions to small satellite systems/missions development and analysis.

Some industries have embraced MB approaches to engineering and decision analysis because of the efficiencies and effectiveness they can offer. Yet several challenges can impede the application of MB approaches to small satellite mission confidence. These approaches and their accompanying tools are not broadly understood or employed in many organizations. Tools and databases may not be interoperable. Some tool capabilities relevant to mission assurance are still in development. And the user learning curve may be significant. Accordingly, an intentionally integrated and coherent development plan must be formulated and implemented if SmallSat mission assurance is to realize the full potential of MB approaches.

Knowledge Sharing Session

The knowledge sharing discussion raised several component database issues to consider-

- What information should the database include? Radiation? Performance? What else?
- It is acceptable to identify components, but linking them to a mission may raise information sensitivity issues.
- Vendors and developers will not share some information.
- Different levels of access will be required to control information dissemination.
- Developers like to share successes but not their failures. (N.B.- this applies to humans in general.)
- There are numerous databases – even within each institution.
- Consider using large satellite systems databases as there is large satellite information that may benefit the SmallSat community.

Best Practices and Design/Development Guidelines Session

See charts 1-11, pg. 7.

TIM attendees agreed there would be value in defining and disseminating best practices and design/development guidelines to the SmallSat community. The practices and guidelines should target a range of users—e.g., developers, sponsors, stakeholders, procurement agencies.

Recommendations will target a broad range of missions—from “do no harm” to missions where their failure would have significant negative impacts. Attendees at the first TIM eschewed applying NASA A through D or Platinum through Bronze risk classifications approaches to categorize these missions, instead deciding to adopt a mission confidence vs. risk tolerance approach. This approach was briefed, and it was decided to stand up a sub-team to mature it.

Attendees stressed the importance of conveying the knowledge in a format that will facilitate and encourage its use. A thick document, for example, could contain rich content, but might see little use. Non-traditional more effective methods should therefore be considered. One approach suggested is a tool such as an expert system tailorable to users’ level of expertise that would that would intelligently overlay knowledge bases and provide the information the user seeks—e.g., a “TurboTax” approach.

The topic of databases was raised again. Numerous databases that incorporate valuable content exist but are not widely known. The NASA Lessons Learned System (https://llis.nasa.gov/) was raised as an example. How information relevant to the Initiative is disseminated should be informed by how such systems are utilized.

Next Steps Discussion

See charts 12-23, pg. 8.

A Best Practices and Design/Development Guidelines sub-team was established to address the following actions:

1. Mature the mission confidence vs. risk approach suggested during TIM-1;
2. Offer recommendations on the how knowledge will be conveyed to the user (e.g. an expert system, wiki, document); and
3. Offer implementation options for the knowledge conveyance approach the sub-team recommends.

Catherine Venturini from The Aerospace Corporation is leading the sub-team.

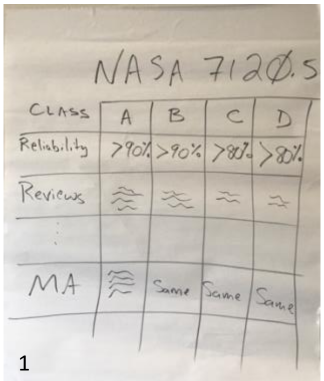
John Evans will lead a webinar addressing MBSE’s capabilities in the context of SmallSat mission assurance.

The next TIM is tentatively scheduled for February 2018. The Aerospace Corporation may host the event.

Acknowledgment- Thank you Elizabeth Klein-Lebbink and Florence Tan for contribution to the TIM-2 notes.

Flip Charts- SmallSat TIM-2
Best Practices and Design/ Development Guidelines Session, 11 October 2017

Charts authored by Linda Fuhrman.



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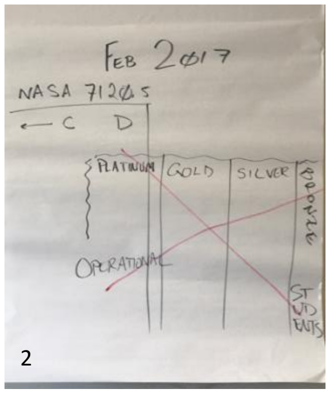

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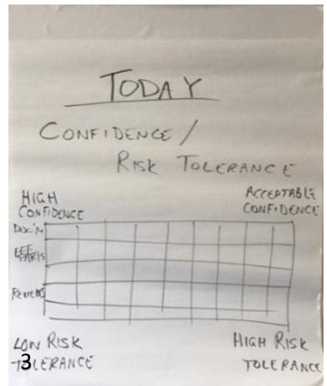

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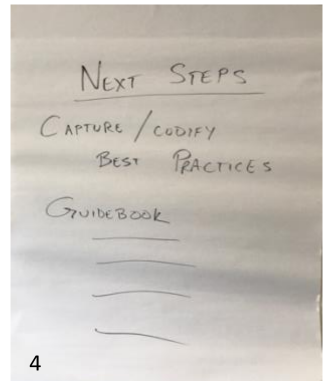

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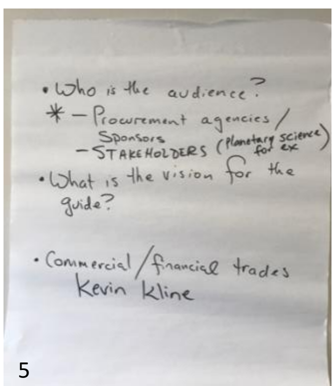

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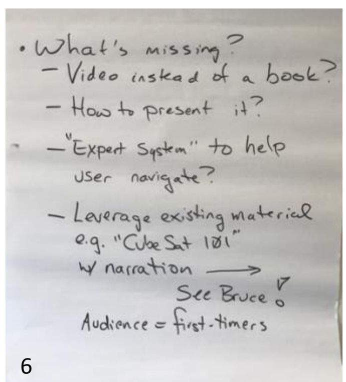

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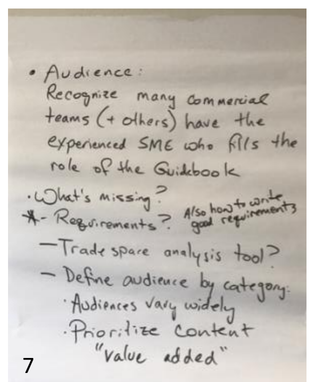

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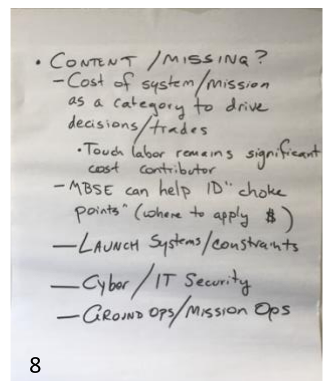

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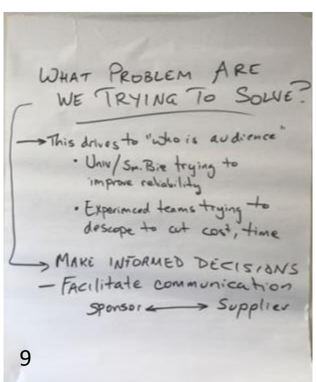

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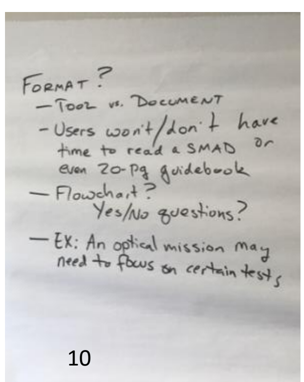

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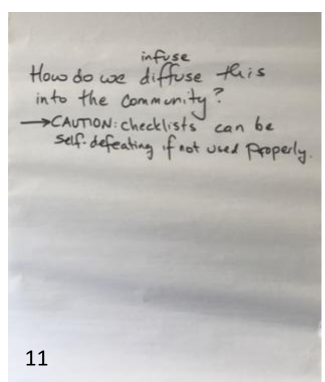

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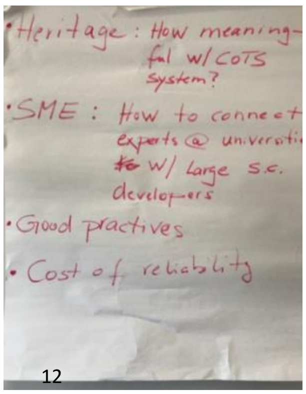
Flip Charts- SmallSat TIM-2
Best Practices and Design/Development Guidelines
Findings, Summary, Open Issues, and Next Steps Discussion, 12 October 2017

Charts authored by Linda Fuhrman and Elizabeth Klein-Lebbink.



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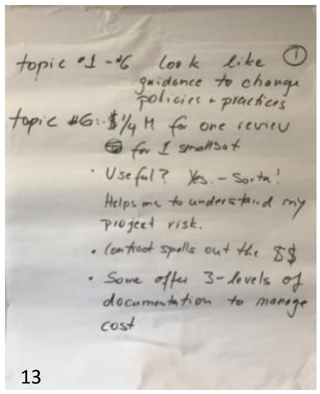

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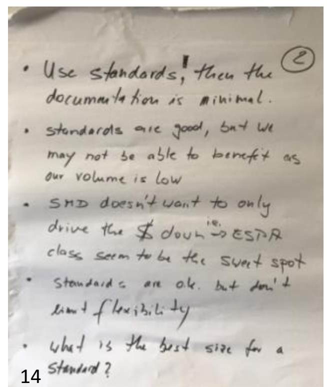

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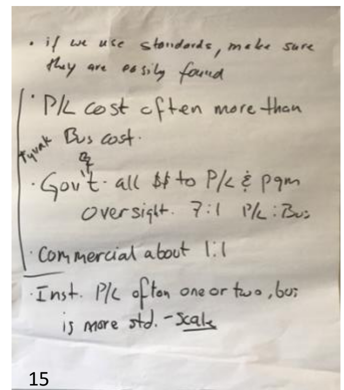

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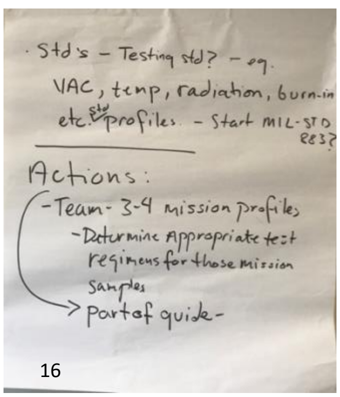

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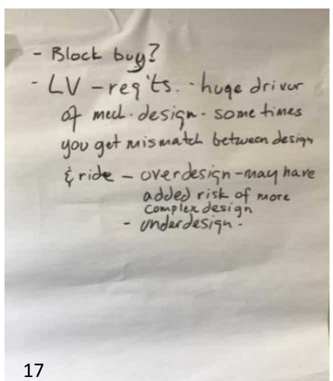

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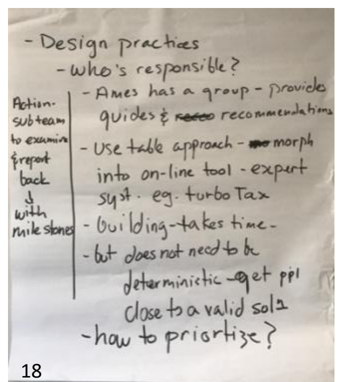

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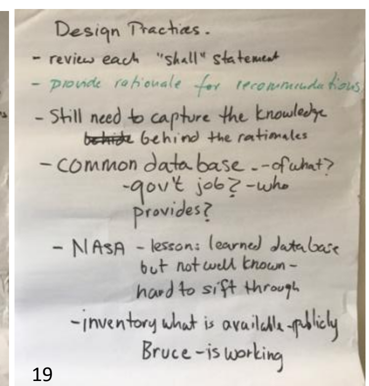

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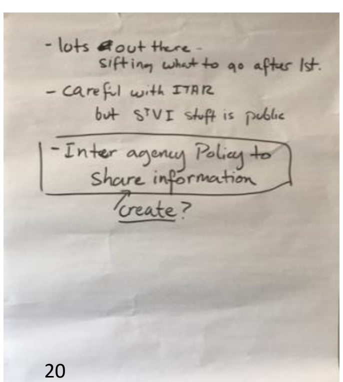

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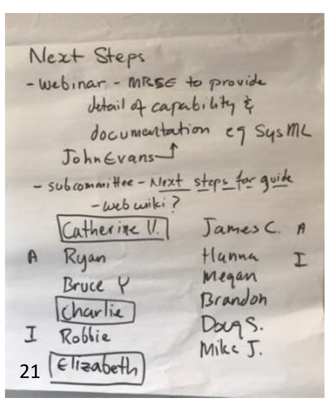

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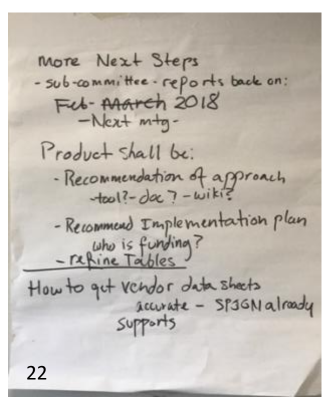

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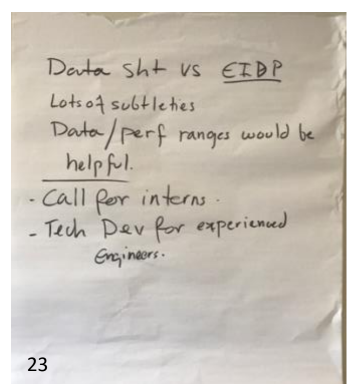

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Small Satellite Reliability TIM-2 Agenda

Day 1: October 11, 2017		
8:30 AM	Check-in- Glennan Conference Room 1O35	
9:00	**Welcome, Logistics**	**Johnson/ Seablom**
9:10	Why are we here? Ground rules. TIM objectives and success criteria.	Michael Johnson/NASA GSFC Michael Seablom/NASA HQ
Lessons Learned from Spaceflight Missions		**Mike Seablom, facilitator**
9:30	10 min Introductory remarks	
9:40	Ryan Miller (Univ of Michigan) —QB50 CDH Development for NASA	
10:00	Chris Ruf (Univ of Michigan) — Lessons Learned from the CYGNSS Mission	
10:20	Randy Rose (Southwest Research Institute)— CYGNSS Spacecraft Component and Subsystem Reliability Lessons Learned	
10:40	Craig Hardgrove (Arizona State Univ)— The Lunar Polar Hydrogen Mapper: LunaH-Map - Mission and Systems-Level Status	
11:00	**Break**	
Lessons Learned from Spaceflight Missions (continued)		**Mike Seablom, facilitator**
11:30	Round table discussion: Common threads and translating lessons learned into actionable recommendations	
12:00	**Lunch**	
Model-Based Approaches to Mission Confidence		**Doug Sheldon/ Harald Schone, facilitators**
1:00	Harald Schone (JPL) – JPL Model Based Reliability Investments	
1:20	Michael Vinarcik (University of Detroit/Mercy) – SysML Modeling in the Automotive Industry (remote)	
1:30	Jesus Mata Castaneda & Natalie Matevossyan (University of Detroit/Mercy) – Vehicle Feature Complexity Modeling (remote)	
1:50	Robert Kraus, George Papaioannou & Arun Sivan (Ford Motor Company) – Application of MBSE Principals to an Automotive Driveline Sub-System Architecture (remote)	
2:10	Art Witulski (Vanderbilt University) – GSN/Bayesian Networks in Small Sats (remote)	
2:30	Full session discussion	all
2:50	**Break**	
Knowledge Sharing		**Bruce Yost, facilitator**
	Bruce Yost—Knowledge Sharing, Website Architecture	
3:00	Catherine Venturini (The Aerospace Corp.)— An Aerospace Perspective Improving Mission Success of CubeSats; Improving Mission Success of CubeSats Product Overview	
3:15	Ken La Bel (NASA/Goddard Space Flight Center): NEPP Perspective data and knowledge repositories	
3:30	Sue Aleman (NASA/Headquarters)— The OSMA Perspective	
3:45	Open Discussion	all
4:30	End of day open discussion & action item recommendations for "Open Topic" session. Review 'parking lot' notes for suitable open topic discussions.	all
5:00	**Adjourn**	
7:00	**Dinner:** *TIM Dinner plans to be announced*	**all**

Day 2: October 12, 2017		
Day 1 Recap		**Michael Johnson, facilitator**
9:00 AM	Day 1 findings, Questions, Issues, Success Criteria Check Day 2 Plans	all
Best Practices and Design/Development Guidelines		**Elizabeth Klein-Lebbink, facilitator**
9:15	Linda Fuhrman (MIT Lincoln Laboratory)— Debrief of Best Practices/Development Guidelines Recommendations from TIM-1	
9:30	Linda Fuhrman— Analysis of CubeSat Reliability	
10:00	**Break**	
Best Practices and Design/Development Guidelines **(continued)**		**Elizabeth Klein-Lebbink, facilitator**
10:30	Catherine Venturini (The Aerospace Corp.) — Improving Mission Success of CubeSats	
11:00	Elizabeth Klein–Lebbink (The Aerospace Corp.) — SmallSat Best Practices Implementation Example	
10:30	Open discussion	all
12:15	**Lunch**	
Open Topic		**Harald Schone, facilitator**
1:15	Round table discussion of top three topics as identified on Day 1	all
2:30	**Break**	
2:45	Continued round table discussion of top three topics as identified on Day 1	all
Findings Summary, Open Issues, Next Steps		
3:00	End of day open discussion & action item recommendations	Pat, Michael, Harald
3:30	Adjourn	