Small Satellite Reliability: A Public Private Initiative
Technical Interchange Meeting-3

May 3-4, 2018
California Polytechnic State University

Thursday May 3, 2018

Welcome, Logistics

Why are we here? Ground rules. TIM objectives and success criteria. Results from previous TIMs.

Key Speakers: Michael Johnson/NASA GSFC, Pat Beauchamp, Harald Schone/JPL

We want to make small satellites a platform that will allow us to fly missions that are more reliable. What are the steps and processes that will us to achieve these objectives? If we put our heads together collectively (government, academia, and industry), we'll get there. Sometimes the government alone isn't as effectual.

Ground rules:

- All perspectives are important and should be heard. Participants should feel free to offer perspectives and ideas. Folks who have not worked these missions can offer ideas that could be game changing. Nothing is too crazy. Want to hear from them!
- Success criteria – we have been trying to develop guidelines and practices from components to missions. We want to present what we've been working on the past couple of months to see if we are on the right track. Are we missing something? Are we on the right track? We will probably need another TIM to close this out.

We will be looking at best practices and a design guidelines perspective, as well as a model-based perspective.

Need to share information in an efficient and effective manner so that others don't make the same mistakes.

< A show of hands indicates a breakout of the assembled group into approximately thirds with representatives from government, industry, and academia. Maybe a few less from academia. >

TIM-3 presentations will be posted on the S3VI website after the authors approve their release.

The Science Mission Directorate (SMD) realizes that if CubeSats are going to a distant target in the solar system or beyond, we need to understand the steps we should take to be sure they are successful.

M. Johnson: Yes, we are trying to take in different objectives and approaches, not just NASA's. It's not just about deep space. The objective is to raise the issue with the entire community.

The lessons learned session will inform the afternoon's best practices discussions.

Lessons Learned from SmallSat Missions – Pat Beauchamp, Facilitator.

Even if we don't fly a "CubeSat" form-factor, the miniaturization of all the subsystems are still important for SmallSat applications.

Lessons Learned Overview- Michael Swartwout (St. Louis University)

Points:

- Census Update
- Will highlight what is not working as far as the taxonomy goes

Mike has been looking at this for 10 years. He is including all the spacecraft that are secondary payloads that are not in charge of the destination of the spacecraft. Looking at 100's per year.

There are now launches that *do* control the destination. Getting dozens on the same launch that are deciding the destination.

Mass only works to a point. Once you get to an ESPA-limited mass the design drivers change. Can't make a change in the volume because of the launch vehicle constraints.

All of Mike's data is publicly available. He aggregates available data. The US builds most of the SmallSats across the board.

SpaceX Falcon – almost all US programs have launches off the Falcon. An effect of US Space Policy is that we have to launch on US providers.

Action Item: E. Agasid: In the US segments, is the data breakout available to show the representation between US government, academia, and industry? M. Swartwout: No, it's not available right now on the public facing page. But there is an internal page where we could look. < Follow-up needed to share this information.>

Mike has better data on CubeSats right now so he'll stick with these in this talk. He does simple heuristics.

Above 500km we see orbital lifetimes go up. Under 400km you need to deorbit in 25 years.

500km and sun synchronous orbit – there is a correlation with Planet because of the Indian flight. Most of these are commercial constellations at 500km.

Small satellites are coming with a different set of constraints. Robustness – being able to change to a different orbit. And recognition that the rocket won't wait for you.

P. Beauchamp: There are cultures associated with different organizations. From a government perspective, we are trying to understand the cultures. Sometimes these cultures want something new all the time, but we want it to be reliable instead. Is the culture changing?

- M. Swartwout: There is a set of people who have a platform that are seeking NASA contracts and customers since they are getting more comfortable. Sometimes the mission assurance component isn't there even though they are getting money because they have a little experience. Not really funded to ensure mission assurance.

- D. Lewis: Is anyone tracking what went wrong on any of these CubeSats?

- M. Swartwout is the only one tracking, but he's not able to track to this level very well. If you are a secondary on a launch you don't know that you're alive during launch or 20 minutes after. Having more telemetry on the spacecraft will help.

- There are challenges for these spacecraft since they are Class D, or lower. We need something formal that goes beyond this. We have a hard time with reliability expectations.

- NASA is rewriting Class D. JSC has a 1E, GSFC has created some sub-D classes on their own.

- NASA has 7120.8. They classified the CubeSats as suborbital early on.

- P. Beauchamp: Tried to get 7120.8 rewritten for CubeSats, but it wasn't supported.

- The mindset of the developers - their approach to mission assurance varies between hobbyist, crafter, industrialist, SmallSat constellations. Industrialists build SmallSats like they are building a larger spacecraft; crafters have higher risk tolerances than industrialists, and SmallSat constellations – there are only a few in this category.

- Tracking Mission success parameters: constellations are thrown out of these calculations. 2/3 of the hobbyists are lost in the first few days. Most hobbyists only build one SmallSat. These include universities. Probably not worth spending much time on these because they'll only build one. Few hobbyists graduate to crafters.

- University developers and crafters are hard to fix, but Mike has advice for them: it is harder to pull off than you think. If you have a 6-month schedule that will slip to 2 years. Functional tests early in the development cycle go a long way, if they do it.

Action Item: P. Beauchamp: We need to get people to start to send Mike information without asking them to give away secret sauce. What will it take to get people to share this data? How can we ask for the information that is not giving away the store?

Home grown systems – what are the failures for these compared to those of the government?

If launch providers would allow the secondaries to get data while on the pad, that would provide a lot of data.

Orbital Clutter

CubeSats dominant source of secondary missions.

For ESPA-class missions, volume matters more than mass.

Russia/India more commercial for launches. Almost all launches from USA are U.S. missions.

Most CubeSats in circular orbits, 400-500 km. Still looking at only hundreds of objects compared to rest of debris, but we are growing.

Different constraints lead to a different design approach

Launch agnostic; the rocket will not wait for you. Low cost but still want results.

You can spend $10M on a CubeSat with similar performance as $1M.

Discussion of culture: Academia: funding 1-2 year cycles, not being funded for mission assurance. NASA: CubeSats fit in Class D or lower. Need to be able to communicate reliability expectations for community.

NASA is rewriting NPR and is interested in feedback on document. Lots of different opinions on sub-class D categories for CubeSats.

New taxonomy- attempt 1

Hobbyist- no real experience, ad hoc practices

Industrialist: experienced builders of big s/c, standard space system practices w/ some truncation

Crafter: experienced builder of small s/c; streamlined practices, experientially developed. (higher risk tolerance than industrialist)

Constellations: ad hoc implementation of orbits; s/c and launch costs effectively free.

2017 year of the constellation! Witnessing either commercial validation of CubeSat platform for ad-hoc constellations, or the beginning of the great CubeSat dot-com bubble

Mission success

Losing about 10% to launch; ⅔ of hobbyists lost in first 30 days. Industrial and crafters fewer losses. Crafters more losses than industrial but ambitious tech infusion.

Hobbyists have very high early failure rates, and usually only build 1. After 3-5 CubeSats, graduate to crafter.

Among all spacecraft developers, 12 groups are responsible for about 2/3rds of all the CubeSats flown. Half of those are constellations (Planet and Spire), with the rest Crafters.

Implications and future work

Secondary s/c occupy different part of risk-cost-performance spectrum. Mission success tracks well with I&T processes and risk tolerance.

Need full functional, vibe, DITL testing...early in the development cycle.

Dellingr- Larry Kepko (NASA Goddard Space Flight Center)

- Overview
  - SmallSats interface between 7120.8 and 7120.5; struggle to balance reliability against cost and schedule.
  - SmallSats stress every point on implementation chain
  - See 2017 and 2018 SmallSat papers
- Dellingr Ops
  - Turned on inside ISS; battery drained; after deployment from ISS antenna and magnetometer boom deployed.
  - ACS started misbehaving Nov/Dec (anomalous gyro, GPS unresponsive, in-house fine sun sensor noisy)
    - Novatel GPS Rx- others have had problems. Worked great for first month then it failed.
  - January started seeing a lot of errors on I2C bus. CPU difficulty talking to subsystems. By late Jan s/c had basically frozen. Were able to talk directly to s/c via the radio without

CPU. 13,000 resets over 10 days. Root cause, reproduced on the dev unit, is if Nanomind is unable to communicate with I2C devices it crashes and reboots.
    - How did they get Dellingr back? 3rd Gen Clyde has watchdog. One of engineers hooked up radio to CPU and sent CPU reset command for 7 minutes during a WFF pass. Lack of I2C triggered an EPS reset, and turned off reaction wheels.
    - Flatsat is invaluable for anomaly resolution.
    - Uploaded software patches to keep RW off/on. RW are now working just fine, without errors, for unknown reason.
    - Developed and tested Bdot algorithm and uploaded to Dellingr, now zero spin.
    - Mission Ops: Need to be able to provide uploads.
    - Tech demo; tried to minimize science requirements.
    - Cadet radio data deleted twice. Don't know why. Cadet froze once; built in a 25 hour reset that saved it.
    - Things that increased reliability/resiliency: multiple FSS, in house ACS, cFS, flatsat, 25 hour rest, ability to talk directly to radio.
    - Things that would be nice: power reset capability (backdoor), better uplink and full duplex radio, ability to turn off and isolate subsystems, a full time team and trending.
    - $4.2M for bus (excludes payload). Reproduction of Dellingr would be $1.6M. Had 4-5 personnel full time for 1-2 years.
    - See theme over and over again- missions should have at least 100 kbps on uplink in order to send patches/FSW fixes.
    - L. Kepko is writing all of this up into a paper for the Small Satellite Conference.

MIT Lincoln Laboratory CubeSats- William Blackwell (MIT-LL)

- Astrosphere sounding CubeSats. Have been flying microwave sounders for years now.
- ATMS: makes measurements of the atmosphere.
- Delivering hardware for TROPICS next year.
- MicroMAS-1: Worked for about a week. Verified power systems, ADCS, but unable to turn payload on.
    - High risk posture, schedule/budget constraints,
- MiRaTA: funded by ESTO. Worked for about a month.
    - Didn't have full mission success
    - Lessons learned; careful with I2C and EPS so that we can reset. Undervoltage event with batteries.
    - PIC had to be alive to work with Cadet.
    - Design did not allow recycling EPS.
    - Lots of mods to Cadet radio.
    - Disney channel was transmitting 100W nearby and interfering with someone else's UHF uplink. Should hook up broad spectrum analyzer and measure for weeks.
    - I2C in general shouldn't be used for critical signals up and down entire board stacks.
- MicroMas-2A
    - Learned from previous two missions. Risk reduction/pathfinder for TROPICS.
    - Fantastic data from payload
    - Lessons learned: everything worked fairly well. ADCS functional with some anomalies. Solar charging magnetic field interfered with magnetometers.
    - Early orbit ID: could tag, GPS for self-location
    - Launched on PSLV- we were able to work with State Dept and get an exception.

- TROPICS
  - Class D mission, testing flight hardware now. 6 satellites in three orbital planes.
  - Class D has been a challenge. Trying to tailor to find correct balance of process versus innovation. New guidance from NASA Class D in the right direction.
  - Suggestions for managing Class D: Simple information up front; allow scalability in level of efforts; strong teams are key for smaller programs.

AeroCubes- Richard Welle (The Aerospace Corporation)

- Aerospace developed software upload procedures in 2011 and used it on all satellites since.
- Ability to do software uploads is uniform across AeroCube missions and is very valuable.
  - Very difficult to forecast all the situations that you'll run into on orbit.
- It's valuable to have multiple telemetry channels to get data. Good to have a backup radio. They now fly two on each mission.
- AeroCube 3 – successful
- Active projects: AeroCube 4,5,6,8 then OCSD (AeroCube 7). Had a software upload anomaly on OCSD.
- OCSD: Lasercomm downlink demonstration. Pathfinder launched 2015 (mission of opportunity to fly engineering model); two flight units launched Nov 2017.
- OCSD-A (pathfinder)
  - Software update made ACS main microcontroller permanently unresponsive
  - Flight upload different than V&V b/c it occurred incrementally, and between contacts the vehicle executed a regularly scheduled power-cycle.
  - With inability to control ACS, unable to turn on lasercomm downlink or laser range finder payload.
  - New process uses bootloader to reduce software upload risks.
  - Bootloader does not patch itself, but can be patched from main software if necessary.
- Value of reprogrammability
  - Many of missions would not have been able to achieve full mission success without ability to reprogram
  - Vital to allow workarounds for unpredictable events, on-orbit cal, and bugs not caught during ground test.
- Are high tumble rates on ejection normal? Probably not. First out of tube sometimes have a very high tumble rate.
- Would better requirements upfront have prevented the upload issue? Yes, you might find that your software upload capability isn't robust.
- For OCSD B/C: have not yet done data transmissions to the ground. Just have seen the laser on the ground.

KeystrelEye- David Weeks (US Army Space and Missile Defense Command/Army Forces Strategic Command (Radiance Technologies/SETA))

- SMDC-1 went up in Dec of 2010. Full success, except launched and deployed at 301 km and only had a 35 day lifetime. Accomplished all of mission objectives
- SMDC has now flown 12 satellites, 11 of them are CubeSats.
- KestrelEye released in November from ISS. Lots of checkouts since then.
  - Star tracker delivered late in program and not tested as much as would've liked.
  - Independent Review Team a big help (but sometimes helped slow things down instead).

- KestrelEye 50 kg class, 25 cm primary mirror, built 450-550 km circular so imaging of better than 1.5 m GSD. This is great for tactical Army. Direct imaging to handheld device in theater and downlink in theater.
- One of contractors chose propellant that couldn't get approved (not built to DOT standards- couldn't get transported on ground). Another problem was battery that contractor chose; if you go to ISS, you have to meet their safety requirements.
- MAI other contractor. Star tracker recessed to avoid stray light, but there was still stray light issues that had to be worked out operationally.
- Finally got cover off telescope last week, but lots of cloud cover. Did get one good image.
- Now authorized to build 3 planes, 6 sats each, will include IR also. Waiting on final approval but it looks good.

The Lunar Polar Hydrogen Mapper: LunaH-Map: Mission and Systems-Level Status—Craig Hardgrove (Arizona State Univ)

- Planned for SLS launch in late 2019. Will discuss lessons that we've learned already.
- Mission is lunar neutron spectroscopy; objective is to fly similar instrument to what's been flown on previous planetary science missions but at lower altitudes and with its own dedicated bus.
- Crossroads of CubeSat and traditional gated engineering development
- Tailored 7120.8 mission.
- Fluid design; no flight spares approach; able to calibrate with integrated system
- (comment from group) Rad testing commercial devices expensive; should find way to reduce those costs
- Components and subsystems for deep-space are new. Schedule slips are common; schedule slip on SLS.
- Design/test/build is necessary but tough (cost) for deep space (propulsion; communications)
- Long duration thrusting – are you doing anything special for this? How are you looking at longer duration operation?
    - 40,000 hour life testing is planned for the propulsion system. We want to understand the capabilities of the system.
    - Will be doing 'day in the life' and ORTs. LunaH-Map is partnered with JPL and will communicate via the DSN.
- Propulsion system uses a gimbaled thruster to desataturate momentum. Developed a new neutron spectrometer. They have a flatsat with a radio, science instrument, solar array gimbal, C&DH, EPS, ACS and propulsion. Components are EDU, EM or emulator. Will be calibrating the instrument at the spacecraft level.
- Lessons learned
    - Work with SLS to avoid interface issues.
    - Documentation – everything at TRL 6 when they launch. Some already are.
    - Holding gated reviews.
    - Radiation testing commercial devices – is there a way to reduce testing costs? Probably.
- Few project level resources to support levying requirements on subs. Flowing these requirements to subs is expensive.
- DSN has only preliminarily planned communication opportunities and DSN contacts yet. For traditional interplanetary missions, we'd have this by now. Deep space missions typically require critical propulsive maneuvers. Comm opportunities that "ride along" with primary spacecraft

comm opportunities are beneficial (i.e. MarCO), but on SLS this is challenging with the large numbers of EM-1 missions all deploying within several hours of one another.

- C. Day: EM-1 has 3 missions looking at the same water? LunaH-Map will help to understand the sub-surface bulk distribution of hydrogen (associated primarily with rocks/soils), whereas the other missions are looking at different aspects (i.e. surface abundance associated with frosts) of water ice.

ISARA- Dorothy Lewis (Jet Propulsion Laboratory)

1. Demonstrate lot cost, Ka-band high gain antenna (KBA) to enable up to 100 Mbps downlink from LEO. >32 dB gain. Has demonstrated all L1s and is 100% mission successful.
2. Lessons learned
    a. Start NTIA/FCC license early; be aware of changing rules in govt bureaucracy
    b. Ground station development- plan far ahead, and make sure you have something to test the station against.
    c. Re-evaluate plans as necessary to keep things simple -what do I actually need to do to meet L1 requirement.
    d. Holes drilled in antenna PCB fab for solar cell installation to mitigate "risk"; vibe caused dot pattern (conductive material) all through EM hardware. The lessons learned here is don't let anyone insist on doing what you don't want to do. They drilled 6000 holes in the FM and EM that had to be filled by hand.
    e. Should have added temp sensor on antenna wing. Add more telemetry. Do not make primary comm antenna a deployable.
    f. Everything went through the environmental campaign and nothing went wrong. They later found that the EM antenna wouldn't deploy. They learned that a wire was exceeding its temperature limit and was heating beyond the stress point so the EM wasn't deploying its antenna. They went back and looked to find that the FM antenna hadn't deployed either.
    g. Make sure approved plan in place prior to mission operations
    h. Keep it simple on the requirements. No radio on ISARA which reduced the testing, etc.
    i. Be aware when your requirements change, whether your ops plan needs to change.
    j. Noise at the station can drown out the mission signal.
    k. Adding more telemetry would have been good.
    l. Do not make your primary communications antenna deployable. If it doesn't deploy you'll never make it through primary communications.
    m. Do your day in the life, take quality photos as you go, don't rely on analysis, don't skimp on reviews.
    n. Doing conical scans on orbit to identify the peak is a requirement.
    o. Is the team trying to modulate the tone? No. Level 1 is to identify the peak antenna gain. Reflectarray is flat and passive. It is just a CW tone. Acts the same as a parabolic dish.

Best Practices and Design/Development Guidelines – Catherine Venturini and Lee Jasper, Facilitators

Overview

Originating from TIM-2 discussions, there was interest in capturing best practices and design practices for small spacecraft, as well as determining how to disseminate this kind of information. The subcommittee was established for these purposes and is comprised of individuals from government and industry.

Approach to sharing: The subcommittee didn't want a static knowledge base, but possibly a web-based tool. A SharePoint site with wiki pages was developed and they added mission assurance and reliability pages. The starter infrastructure utilized some Aerospace structure. A diverse group of people supply the content.

There are 35 topic areas included in mission assurance and reliability. Whether they are all applicable to SmallSats is under discussion.

Twenty-five of the thirty-five topics have draft content available in the web tool. Content includes: scope, references for each area of best practice. 2 examples were provided.

The Reliability tool is term searchable, web-based and interactive. Catherine and Lee are looking for feedback from this group.

First Question: Candidate Mission Architecture?
Second Question: Key technical challenges and risks?

- Are boxes pre-filled out? They are for novice users to give some guidance.

- Is this intended for the program office, or the mission folks? How do you make a novice mode for all different kinds of users? Maybe create a question asking what kind of a user are you?

- A lot of novices will go and read this and not really know what it means. How the questions are scoped is being worked.

Once a recommendation is written in the interface it can cause issues. Can we make a minimal set of recommendations for consideration?

Would like to see some of this tied back to what mission success is. Help guide users through the process to help them determine what is worth the money to do.

Its important to figure out early how to make this open source for the training session. The TIM-3 participants can help develop the key questions. Maybe we don't need a TIM to work through this. Provide links to documentation – like publicly available tools and educational resources.

The topics are the traditional topics. There isn't a system resiliency topic. We need to have a clear definition for what resiliency is. It seems to be the word of the day.

If we're a supplier and want to penetrate the CubeSat arena – is it possible to use the tool to find out what the folks using the tool need? Yes, Catherine thinks this is something we want to do to start dialogs.

Small Group Discussions
Four small groups discussed and captured answers to the following questions:

- What reliability topics areas are the most important to your organization?
- What do you consider makes a high-reliability component, subsystem, bus, or mission?
- What design practices are key to mission reliability?

- What sections/elements of reliability would you want to learn more about?
- What are key questions that you would ask, or not ask, related to reliability?

Small Group Report Outs – Summary

Facilitators- Michael Campola, Tony Divinti, Lee Jasper, Jim Lohman, Robbie Robertson

Group 1 - Mike Campola

- You need to know what you want to get out of the test you're going to perform.
- Design with margin in mind and know where the hairy edge is.
- Know that you have unknowns and that you need to deal with them.
- Need to know more about prioritizing environments.
- What is the metric of success criteria you are dealing with? Need to clearly define mission success criteria.
- Need to be writing the web tool for experience people too, including those responsible for schedule and cost. This is a learning environment for students.

Group 2 – Robbie Robertson

- Know the elements of the design that you can't test for. Radiation testing is costly.
- Derating and margin
- If you're going to waive some of the traditional processes, show that you understand what might come of that.
- Have the web tool provide high-level guidance. Point users to a value.
- How do you sanitize proprietary data? JPL has a proprietary database but the content is starting to get stale. As long as we know how to capture proprietary data, we might be able to figure out how to share it.
- Isn't one of the purviews of the government to take care 'of us', so that they should be able to share their knowledge with us? No, you can't legislate that unless its safety related.
- Turbo tax tool – establish a hierarchy of importance when your search results come back with many hits. Review the tool early and often.

Group 3 – Tony Devinti

- It's important to distinguish infant mortality and mission reliability. Good approach to testing.
- Should tailor up.
- If you can think about designing for repair it really helps for fixes when you need to do them. The tool should point to documents that support a highly reliable CubeSat.
- Design for repair means what? Design it for serviceability.

Group 4 –

- Need an informal way of sharing info about good/bad vendors.
- We like flight heritage, it is a way to get high reliability.
- Design practices – flatsats are good to do.
- Higher volume is good for high reliability.
- Beef up the wiki. Software reliability. More about reconfigurability.
- What's not included: cost and schedule.

Full Group Best Practices and Design/Development Discussion

What mission area topics are the most important to polish off? Maybe prioritize some of the areas to focus on the important ones. Should try to get consensus on which path to go down to ensure mission success.

Action Item: Group wants to review the 35 topics to help Catherine to prioritize. Maybe assign dollar value to each? Do a survey online for this? There may also be a few new topics resulting from today.

Drill down tool versus searchable database. Challenge for the tool is the amount of time it takes for the tool to be useful. It might not be useful for 95% of users. Who will benefit from all the work we would do for this? Need to know who the users are.

How do we make sure that the user of the tool is exposed to information that they don't realize that they need to know? The flowchart would do this?

Include a risk heat chart on the side of the tool to show users risk status as they answer questions? For example, if a user selects a deep space mission, with 4 people supporting it, and $1M to spend, the user should rethink their plan.

Possibly have pull downs for duration and for amount of funding available. Let users know what they can do with what they have. Need users to be realistic.

Who will pay for this tool? Catherine to leave to that to Pat and Harald. Where should it be hosted? Can ARC host it? What security plan does it need?

Should we keep the flowchart? Maybe list in it more simple parameters like how much money do you have? Should we list what takes the most money or time? Is that too subjective? Cost versus reward consensus for the group on each mission type and other parameters.

H. Schone: The morning session uncovered that we are overlooking software. Is software a problem that is unique to CubeSats? You almost always have to start from scratch with software and CubeSats. What kind of software standards are we looking for? Software came up in 4 of 6 presentations this morning.

Information assurance and cyber are really important and we've not dealt with them. There are some best practices for information assurance tied to reliability.

No software engineers are participating in this TIM, so that may be the problem. Is there something with software that we should be doing differently? Should there be more built in self-testing diagnosis? Self healing? Something different to what we have in the big birds.

State of health app? If you are developing the software yourself, it's a very expensive proposition.

There is a lot to be done about cost effective software assurance. A lot of the DOA's in space were probably due to software. What can be done? Code Analysis – purchase this for the agency to use? Its $25K per year. No CubeSat developer at NASA will buy this alone.

What are the important things we want to do? We have workshops for solutions, not problems. Maybe we go back and ask the customer how we arrange these vendor contracts. 11 companies make up 60% of the vendor base.

The way we let contracts now, we tell them what the product needs to do functionally, but they also explain how they achieve reliability via NPR's, testing, etc.

Would the vendor assume the risk for their parts? If the parts fail, the vendor would need to pay for the mission? Don't know of any vendors who would take that contract.

Full Group Day 1 Discussion, Actions, Day 2 Objectives
P. Beauchamp: System engineering and the lack there of. Are we trying to solve the right problem? Most of the time we think that it's how you put the parts together that cause the problems (system engineering).

Vendors put a lot of emphasis on the requirements review to understand what the customer wants.

Design and system engineers are very important to the process.

Are there best practices for requirements flow down? There is extensive documentation for systems engineering processes. This isn't the purview of this group though. Within the subcommittee they collect all of these documents, but don't focus on them.

Talk about this tomorrow. There is a minimum amount of requirements flow down. Need to determine how critical it is.

The challenge is that there is resiliency that is traceable to requirements, then there is resiliency that isn't traceable to requirements. Architecture versus engineering.

Adjourn Day 1

Friday, May 4, 2018

Day 1 Recap, Findings, Questions, Issues, Day 2 Plans
Key Speakers: Michael Johnson/NASA GSFC, Pat Beauchamp, Harald Schone/JPL
No one wants to have to perform a hard reset of spacecraft. Is a robust, reliable reset circuit something that we could provide to the CubeSat community? In the past some have added a reset button. For this they had to drain the battery to shut off, then let it come back up. This is not the best approach. If we do something like this it would need to be done well and tested.

D. Mayer: The assembled group has representation from each sector (government, industry, academia) by about a 1/3 each. Listening to the proposed products, there isn't a clear charter and understanding of who our customer is. The desire for recommendations on a reliability standard and level of workmanship depends on what reliability we are aiming at. We need to focus our efforts.
M. Johnson: We should be able to do this. We need to come up with an approach for mission assurance.
D. Mayer: We are still forming the problem statement. What is the problem we are trying to solve?

L. Jasper: Are we doing mission assurance or reliability? Reliability is a subset of mission assurance.
M. Johnson: As soon as you introduce architectures you move to mission assurance. Reliability is different across mission classes. We need missions that we have confidence will be successful.
L. Jasper: Risk posture is important to know.

There are two classes of mission assurance. When we look at workmanship and reviews, there is nothing unique to CubeSats. What differentiates CubeSats is the fact that we are using components that aren't traditional. We intermingle two risk categories. We are limited in budget and so we don't do some things.

L. Jasper: Usually CubeSats are cost constrained missions and you accept certain things.
T. Diventi: Within the bounds, we use the data we get to prioritize test, reviews, etc.
M. Johnson: If we are successful, then the box will expand in reliability and capability. We expand the box by interaction with our industry partners - the continuum of what gets done for mission assurance. There are very different mission objectives – university CubeSats to Mars missions in the Class D, C etc. Need to be specific to the mission objective.

Customers don't really know what they want. Looking forward to the survey to decide what 35 topics we should select to focus on. Need to select 6 that we should work on. Can also write in topics. Survey's need to be signed to be considered. *<Written survey provided to TIM-3 participants to select 6 topic areas from the list of 35.>*

Model-Based Approaches – Status and Next Steps - Harald Schone, Facilitator
Why is this an important activity? Risk postures for CubeSats are all over the place. We have a problem communicating the risk posture. Air Force is working on developing the risk categories. In the past it was easy because we had documents telling us what to do, but now they don't apply. At a minimum you want to state that you have a notional design, and its still heuristic. You have knowledge on what components you want to use and all of a sudden you know something. There is no correlation on the work you do to reduce the risk posture and buy down risk. If you have enough money, you can do reliability, but we don't have a lot of money.

Using modeling to support your analysis is something we are trying to do. Lunar Flashlight used this. Functional Reliability Modeling Capability. UCLA has a tool called IRIS that is arranged in 3 blocks: the event sequence diagram; fault tree diagrams; and Bayesian networks. From the point of event sequence and fault tree, we have documentation on what could go wrong that can be shared. You can do this before you've even let the contract. You can also put a layer on top of this to add probabilities and distributions of failure behavior. When you have the functional description for the system, you can see the reliability function of the system.

ASU has built compact models for analog systems. Latch up and total dose for rudimentary components.

Modeling is a way of knowing your risk drivers quickly. We can create libraries of blocks for the CubeSat that are fairly reusable. We can build functional diagrams and fault trees for reaction wheels, etc. This would be an initial step. Is there a value in creating a reliability library that can be reused?

Question: Do the curves come from the fault tree? Those were entered into Bayesian networks that were tied into the fault tree.

Each box has failure probability modules – would they have to rebuild the model for each new mission? Environment and the notional CubeSat you want to use will drastically change each fault tree diagram that results.

How pervasive is the use of models in this industry for reliability and risk? *< Not many hands raise>.*

Some SmallSat customers do want it. Might do a Monte Carlo, Spice model to see if that will cause a failure in the fault tree. Model the system, perform a Monte Carlo, take the results of that into Spice, then that output goes to the fault tree.

There is a lot of information on COTs parts out there, data sheets. When you have a small project, you're not going to devote 10% of your project to one analysis. You can break the bank on one high fidelity model.

Make the library open to the community. Provide an open source reliability model where people can add to it and share would be a good thing for the community.

Would we put these into SPOON? Who would make the reliability assessment of all the parts? Big question.

The Bayesian approach can have multiple paths. The problem with Bayesian is that you need something to base it on. It gets you to the tall poles.

Modeling is a way of documenting your issues, assumptions.

On MarCO for example, at the start, the probability of un-success was 80% when the mission included 4 spacecraft. When the mission dropped down to 2 spacecraft, the probability dropped to 20%.

Your IP is at a much higher level than the parts. It's no big deal that you use this part or that - its how you put it together. Your IP is in your code.

Some spend two years qualifying a part and they wouldn't want to upload their curves to a library. Could just write Part A, C, B, and not list the part name?

Event sequence diagram will be mission unique, but fault trees might be generic. Another challenge is with the other tools that show one failure at a time. Three or four levels of degradation can still be recovered.

Parts have failed on orbit as well as workmanship. Trying to diagnose the DOA's with no data. The qualification program is good, but we have found bad solder joints. Can't recall workmanship failures, but parts failures.

We go through vibration – but is ESS a more efficient screen? Simultaneous thermal cycle and vibration.

J. Puig-Suari: We say it worked when it launched. Never vibed twice and had things fall apart. How deep was the test if you get a DOA? If we start cranking up the testing, we run the risk of doing testing like we do for large spacecraft.

CubeSats are defined by low cost and low turn around time. Each mission might be unique and some will be a $100K cost and others will be in the millions. You have to choose your own risk posture. Need to give CubeSat developers a process where they can choose their own risk posture. Some may need just a 1-week test before launch.

We can base mission/parts on how much money one has. The tool will let you select down.

Would everyone want to contribute to one of the 35 topics to do mapping into the different mission categories?

J. Puig-Suari: Large production runs improve reliability. Planet does this and they always work. There is a possibility that we do one mission at a time and we'll learn from the first one, then fix for the second one.

RSDO – GSFC tool. Companies could add their buses to it. It still exists, but its aimed at buying much more expensive buses.

Blue Canyon, Tyvak, that is how they get their prices down and the government is buying them because of it. Leveraging their success.

Knowledge Sharing, Communication Plans – Bruce Yost, Facilitator
Recap of the S3VI activities. Swarms for Science and Exploration Workshop occurring – later in the year. High Volume Manufacturing Workshop being considered for the fall timeframe.

The Aerospace Corporation (C. Venturini**)** has been working with S3VI to port SmallSat DB parts to SPOON. Later content from Aerospace's LaunchLog will be added.

Action Item: S3VI web portal to link to M. Swartwout's website from the External Links page.

Next thing is developing SMD rideshare policy for spacecraft ESPA size and above.

Action Item: Move the link to the SPOON database to the front of the S3VI portal.

Action Item: Consider adding/linking to ESA parts database(s). They're good and we should link to them.

CubeSat 101 - Walks developers through CSLI process.

CubeSat 202 – Could address risk posture and best practices. Make it searchable and public. Is it a document with some webinars to accompany it?

What is ESA doing in this area? They are putting together their SmallSat standards. They have tailored standards. Someone should obtain an account on the ESA site.

JAXA, ESA, and NASA attend(ed) the trilateral TRISMAC Conference.

Regarding deep space efforts: one issue is that low Earth orbit CubeSat missions have done really well. The business model makes sense. Now that NASA is opening the door to deep space, there is a void in CubeSats missions that meet that. Academia doesn't have the experience for this so there is a void.

The deep space business case resides with NASA. How do we make an open venue so that we have a pathway to deep space like we do for LEO?

STMD SBIR – SmallSats are a big chunk of the portfolio. Bruce needs to come up with topics. Are there things that small business can do, that we can put into the solicitation for next year? Maybe if we're more clear about specific SmallSat needs. It's broad in areas now. What particular things can industry contribute? They don't usually like building 1 offs.

Reliability and risk posture aren't well defined and the developers will need to determine what risks to take. CubeSats aren't in decadal plans right now, but they could be.

The SIMPLEX has CubeSats in it. The door is opening.

Class D Guidelines – an email came out with information on Class D.

Action Item: Add the 8070 document to the S3VI portal.

Action Item: Look into push notifications for the Reliability Initiative page.

Action Item: Look into monthly newsletters summarizing what is new on the S3VI portal.

Action Item: Collect all relevant reliability documents into one place.

End of TIM Findings Summary, Open Issues, Next Steps, Actions

Key Speakers: Michael Johnson/NASA GSFC, Pat Beauchamp, Harald Schone/JPL
An off hand comment was made yesterday about a brokered database where you can pay for access. It could be a great solution. There is probably a lot of test data in it. How would you get access to it? If you provide some data, but then have access to a lot more data from others, it may be worth buying into.

H. Schone: Could there be a pre-approved parts list developed that tells folks what they can use. Maybe build a consortium that has access to the list. Is there an industry association that does that? Best list is at GSFC. Is there a big space consortium that we can ask to leverage their NDAs and infrastructure?
Action Item: Bruce to ask SmallSat Technical Committee at AIAA.

Action Item: Catherine has done a lot of work on the tool/sub committee. Need volunteers to support the subcommittee.

Did spend much time on the model based stuff. Its important that we start to understand the interdependencies that come out of them on-orbit. Little changes along the way by starting with the easy problems now will help in the future. Can we track what is going on in model based areana? Harald can hold monthly model based assurance status. Biggest bang is to have low fidelity model of the system because it's the quickest turn and cheapest. This is the UCLA tool. Can track assumptions. This group can be part of the review team. Bruce wants to do a CoP talk with the UCLA and Harald / JPL on the modeling tool status/progress.

Action Item: TIM-4 – Hold in November or early December. Maybe do it at CalPoly, or in Denver at LASP. Solidify location and dates.

Is this a valuable TIM? It's challenging that we have different people coming and going. It's good and bad. Need clear goals for TIM-4. It's hard to make progress when you have to bring new people up to speed.

Action Item: We need a software expert to participate in the next TIM.

Action Item: Synthesis key findings from each TIM to post on the S3VI site.

For the next TIM have sessions dedicated to particular topics with experts. Should we discuss targeted reliability issues?

What else?

- Need to get the answers to the 35 topics.
- Need more breakouts during the TIM
- Need 2 full days (on a Tues and Wed, not following the CubeSat Workshop)

Action Item: Hold a TIM-3 out-brief over WebEx/Adobe Connect sometime soon.

Adjourn Day 2