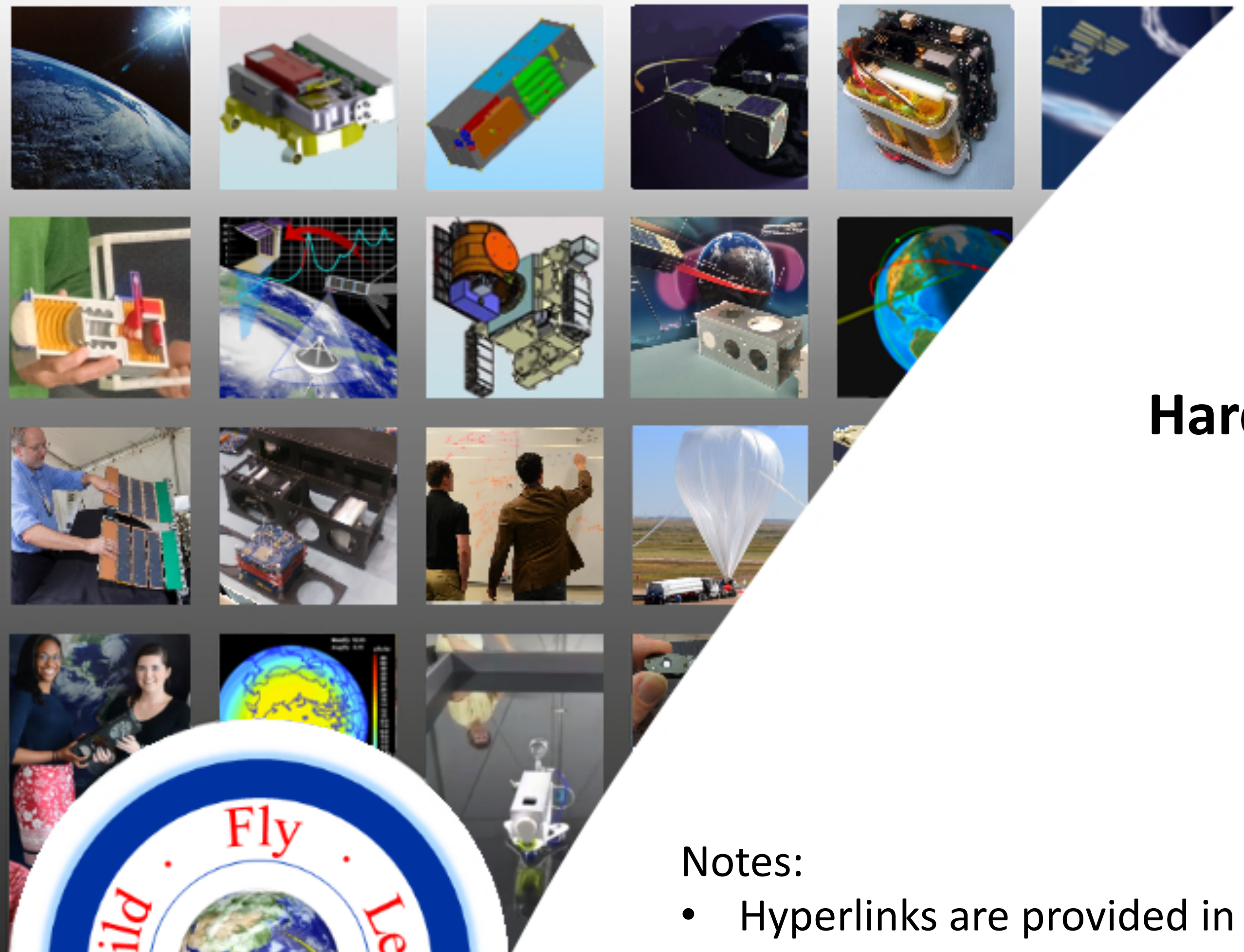

Basic Handling Guide of Small Satellite Hardware for Non-Government Organizations

NASA Langley Research Center

Notes:

- Hyperlinks are provided in this package and a full list of links are provided at the end of this package.
- Links are not endorsements of any one company over others, just a reference that one of the authors my have used.

www.nasa.gov
http://engineering.larc.nasa.gov/

Contributing Authors

- Carrie Rhoades, Langley SmallSat Lead
- Joey Patterson, Langley SMA for SmallSats
- Gene Monroe, Langley Lead Quality Assurance Engineer, and LaRC POC for Workmanship and ESD
- John Pandolf, Langley EEE parts Lead
- Marc Murbach, Ames CubeSat expert
- Ali Guarneros Luna, Ames CubeSat expert
- Matt Mahlin, Langley In-space Structures Engineer
- John Mulvaney, AMA Inc
- Raymond Lueg, TEAMS3/AMA Inc., SHIELDS-1 CubeSat Technical Lead
- Mark Banchy, Langley Software Engineer
- David Keck, TEAMS3/STC, Software Engineer
- Chris Volle, USRA Student
- Nicholas DiGregorio, Langley CubeSat Engineer
- Michael Flood, Langley Electrical
- William Berrios, Langley Mechanical Design

Disclaimer

- This is intended as a supplemental source of information for Non-Government organizations such as Universities and Hobbyists. NASA and other government agencies have their own standards and practices that should/must be complied with per their own instructions.
- It is basic reference for non-experts. Many people spend years on just one area of this guide becoming an expert in their field.
- This guide will NOT make you an expert.
- This guide is NOT a replacement for your Launch Service Provider's instructions or other federal requirements.

- This is not an all inclusive guide – it is just a quick, basic reference guide for people who have little or no experience with space flight hardware.
- SmallSat and CubeSat are used throughout this document. Generally this document is for CubeSats. CubeSats are defined per http://www.cubesat.org/

SmallSat Failures

- SmallSats are new, so many statistics are starting to be generated and there is a lack of sufficient data behind existing information.
- SmallSats generally do not have the system capability to tell the ground what specifically went wrong with their system.
- Most statistics on failure concentrate on hardware and not on handling

- Many failures may occur from improper handling and testing of hardware and not be detected or tracked as such.

Personnel Safety

- Safety is a mindset and philosophy. Its Mechanical, Electrical and possibly Chemical - primarily the two former are more prevalent for CubeSats.

- PEOPLE SAFETY SHOULD BE FIRST IN EVERYONE’S MIND – No compromises!!!

- Mechanically: sharp edges, pinch points and things of that nature that could injure human hands and eyes.
- Electrically: Large Voltages and Currents need to be respected with appropriate handling procedures. No one wants human injuries negating the monetary savings from these small size projects. Large Currents from shorted Li-Ion type batteries would be a great example of fire potential, human injury from skin burns and eye safety.
- Any work with Lasers and High Energy small volume stimulus like Radar needs safety attention, and intuitive applied smarts.

System Thinking

- **Your team needs an agreed upon process to cover how it operates**
- **Basics of the process should be:**
  - What is your risk posture? – What kind of testing you will do? How much failure you can or cannot take?
  - How you will document? – Is there a community workspace for documents or a physical logbook that stays with hardware?
  - How you will handle hardware?: Is Electro Static Discharge (ESD) or cleanrooms required?
  - How you will track and control hardware?: is it confined to a workspace or are people allowed to take it home? What condition is that hardware in – is it all perfect? If not, how is it marked?
  - If your team has high turn over rate: Organize and make sure data captured is easy for someone else to understand. Have them read it and tell you what it means – if they don't get it while you are there – the next person won't understand it when you are gone.
  - What to do when something fails – don't just pull it apart and don't hide it. How to you make sure you learn from them?
  - What are your testing requirements? What drives that requirement and why?
  - What are your Ground Support Equipment (GSE) requirements?
  - How will you analyze and recover from failure events?

Risk

- **What are you trying to do?**
- **What will your stakeholders accept?**
- **Identify your requirements and what you need to do verification testing on.**

General Operations of Building a CubeSat

- **Plan for 3 versions of hardware:**
  - development unit – most of the testing gets done here
  - proto-flight unit – validates any changes found from the development unit
  - flight unit – pristine hardware to be flown
- **Build a flat sat (ie all components laid out on a table and electrically connected but not packaged into the CubeSat box), if possible**
  - Use development hardware first for initial layout, functional testing, and software development.
- **Add the flight hardware components and test the system outside your satellite box.**
- **Build it into your satellite and test the system (usually called functional testing).**
- **Perform environmental tests of the system.**

Handling

- **SmallSats/CubeSats are like flying computers – lots of electronics in a small space.**

- **Improperly handling electronics on desks without proper techniques can microscopically effect the hardware so that it is not detectable with the human eye and it may seem to work fine for a while… but it may fail earlier or fail to function in the extreme environments of space.**
  - Dropping boards causing solder cracks that will be seen in the vacuum and temperature extremes of space.
  - Putting hardware close to EMI/EMC sources can cause improper data.
  - Conductive contaminates could cause shorts in a space environment.
  - Certain chemicals might corrode.

General Assembly Approaches

- **Try to build access into your design.**
  - Software loading port that you don’t have to pull the whole satellite apart to access.
  - Power port – you will need to be able to charge your system.
  - Make it as easy as possible to change out components in case they malfunction and need to be changed out.
  - Tooling access – make sure you can get tools in to assemble/disassemble.
- **Minimize how many times you have to assemble it. The connectors are small and fragile.**
- **If cameras are being used, try to keep the clean by using covers but don’t forget to remove prior to flight (that’s where those red tags originated from)**
- **Perform a basic parts stress analysis. Basically, we don’t want parts operating at maximum stress for the duration of the planned mission.**

Materials

Know about materials selection and outgassing:

- **Types of grease you use is important if you have moving parts. Many will evaporate in space environment.**
- **Watch for material compatibility: galvanizing, corrosive, galling, etc**
- **If you are taking a science measurement, outgassing can coat your lens with vapor deposits that will skew your data.**
- **Planetary probes have addition cleanliness requirements that will require clean rooms.**
- **Review NASA-STD-6016 (Section 4.2) for M & P Requirements for Spacecraft**

PROHIBITED MATERIALS FOR FLIGHT HARDWARE

Material	Reason	Exceptions
Pure Tin (including plating)	whiskers	Tin alloys with a minimum of 3% lead, such as solder, are permitted.
Cadmium (including plating)	Whiskers and toxic sublimation	Alloys less than 1% cadmium by weight are permitted.
Zinc (including plating)	Sublimation, whiskers	Alloys less than 1% zinc by weight are permitted.
Mercury	Accelerates stress cracking of aluminum and titanium alloys	

https://outgassing.nasa.gov/

Tape

- **Tape has lots of uses – holding temporary items like wires, protecting systems**
  - But choose the right tape for the application
- **Use tape that won't leave a residue on ground test hardware –**
  - blue painters tape works for GSE – but don't fly it. It burns.
- **For flight use space tape – kapton with acrylic backing is recommended – but there is always different types available with different temperature ranges**

- **When integrating system – especially power systems – cover terminals with tape during installation. (Then remove the tape after assembly.)**
  - Discharge everything you can when possible prior to integration. Capacitors, batteries, etc
  - Note: A student dropped a standoff between boards and shorted the power system. The board cost was $15k – so be careful!

Electro-static Discharge

- Don’t build on a standard table – especially a metal one – Use an ESD mat.
- Have a ground and use it, when possible in the room where you are assembling and keep people away – damage might not be something you can see but it might degrade your system.
- How to verify ground? - Connecting to the ground of any AC outlet usually good enough
- Wrist straps for grounding are necessary for anyone working within 1 meter of the electronics
- Don’t reconfigure a system while energized – ensure power is removed before unplugging things.
- Direct an ionizer onto exposed electronics whenever insulative material is within 12”

Electronics Workmanship

- **Perform a basic energy trace/barrier analysis on the PCB (Printed Circuit Board). This will help with risk mitigation when designing/assembling boards (i.e., identifying where you could possibly short out a board based on the energy currently in the system).**
- **Bundle wire harnesses and secure them as much as possible. Vibrations of launch are severe and can chafe through wire in no time.**
  - Standard zip-ties should not be used, because they become too brittle in vacuum/space.
  - There are vacuum rated zip-ties, if you need them.
  - Another way to do cable management would be to use white (polyester or nylon) string to tie cables together, but an epoxy needs to be added to keep the knot tied.
- **Wire – Best practice is to use teflon coated (thus high temp) and low outgassing.**
- **Use leaded solder to prevent tin whiskers. But use proper handling precautions and disposal of scrap.**
  - Tin whiskers are a consequence of using tin in a vacuum.
  - Conformal coating mitigates this the best, but should only be used for short duration missions.

Electronics Workmanship

Clearly label grounds and power terminals

- Example of what happens when you don't:
  - Used a pinout diagram for a serial connector to attach jumper wires to power payload from power supply, the pinout was meant for assembly, so orientation was backwards… Power and ground were reversed when interpreting this at the connector on the payload. Result was 24 V into ground side of board. Fried one capacitor and an expensive 5V voltage transformer. Backup soldering pads for 5V voltage transformer made it easy to add a new one. Reverse current protection from capacitor saved the rest of our board.

Ground loops

- Clean ground paths should be designed into your CubeSat – multiple ground loops can cause a troubleshooting nightmare. If you are having electrical issues you can't figure out – check your grounds and try isolating your systems from each other.

Shrink tube materials

- Teflon shrink tube has low shrink ratio
- Polyolefin shrink tubing is an alternative with higher shrink ratio and has a low cost

Electronic components

- **Electrical parts – some have air gaps that will split open either in the launch due to pressure change or in space due to vacuum/temp changes.**
  - An example is Aluminum Electrolytic Capacitors – replace them, don't fly them!

- **Consult a EEE parts person if possible.**

- **Try to purchase from reputable companies.**
- **If possible, use resources like GSFC Qualified parts list directory: https://nepp.nasa.gov/files/28972/GSFC-311-QPLD-031.pdf to understand if parts are truly rated for space applications.**

Electrical Standards

- NASA Standard for Workmanship on Polymeric Electronic Assemblies: NASA-STD-8739-1A
- IPC Standard for accepting electric workmanship http://www.ipc.org/committee/drafts/7-31b_d_610F-draft-Feb2012.pdf
  - How do you verify your soldering and mechanical aspects of the electrical assembly are acceptable?
- Electronics assembly guide handbook IPC-HDBK-001F https://ipc.kavi.com/higherlogic/ws/public/download/4721/IPC-HDBK-001F_Final%20Industry%20Review_Version%202_FINAL.pdf&wg_abbrev=5-22F
  - Detailed instructions and considerations for electronics assembly.
  - Staking guidelines, follow these to reduce chaffing and wire vibration, be sure to create strain reduction loops.
  - Remove any masses of wire/wire bundles.

Testing

- **Test like you fly**
- **Test as much as you can, but be cautious of overtest. These systems generally aren't built to survive for years so testing to full NASA standards is usually not required for environmental testing.**
- **Perform Vibration testing prior to thermal if possible.**
  - Vibration might knock a solder joint loose but functionally the system still looks like it works at normal temps. In cold the joint will retract making your system fail.
- **When possible test with calibrated GSE.**
- **Recommend testing to the** GENERAL ENVIRONMENTAL VERIFICATION STANDARD (GEVS) **standard unless you have specific launch values. Review the durations though – full cycles will get you more reliable but will also stress your system – perhaps past its capabilities.**
  - For instance thermal vacuum I would dial back to a minimum of 1 overtest hot/cold and full operation cycle hot/cold – but more is better for long duration reliability.

Testing Process and Practices

- **Plan out what you are doing. Test like you fly.**
  - **Make a schematic.**
  - **Write a test plan.**
  - **Photograph the setup.**
  - **Have someone else review setup prior to powering.**
  - **Look for safety issues.**
  - **Think about what could go wrong. Prepare for it.**
  - **Photo your test. Video better because people have bad memories.**
  - **Try to use as much like the flight hardware as possible.**
  - **Try not to modify on the fly without thinking it through.**
  - **Keep a log of changes.**
  - **Photograph sub-assemblies prior to assembling into the main payload.**

Log book

- Running commentary or book
- Example Open Item Log:

Record #	Date of Discovery		Discovered by		Corrective Action:			
Issue:								
					Redlined/As-performed document submitted to Config Management? Y / N			
Drawing No.		Installation: Y / N			Tool Calibration No.		Cal Due Date	
Doc No.		Weight:			Task Completed			
WO No.		X			Date	Mech	Insp/QA	
Notes		Y						
		Z						

Customize this based on your system needs…

Post development – prior to flight system assembly

- **Some recommended materials for assembly (not all inclusive)**
  - Conformal coating for boards
    - Arathane 5750
  - Potting Material (filling connectors after testing checkout)
    - Arathane 5753 – potting
  - Staking Material (for tacking bolts and supports)
    - ScotchWeld 2216 A/B epoxy
    - Loctite can be used but there are only certain kinds good for space – it can also outgas – check your requirements and the material before using

- **When using staking materials – it can just be used on the side of the head of the bolt to prevent movement – it does not need to be placed on the threads. This helps if you ever need to remove the bolt – you can break the staking material and then remove the bolt or cut the head of the bold and still have good threads for re-assembly.**

Parts

- **Tag items that are modified or broken so someone else doesn't waste time with them.**
- **Fasteners – Aerospace quality vs hardware store – there is a big difference**
  - Counter sinks 100deg vs 82deg, strength of material, etc
- **Fastener lengths – make sure you can get at least 2-3 threads past the nut to ensure full engagement of the nut and full strength to the connection.**
- **Watch loading countersunk fasteners in shear – they aren't designed to do it.**
- **Edge distance for holes - Generally 2xbolt diameter is a good but for many CubeSat parts you will not be able to do this – check your loads to make sure you won't have an issue.**
- **Material treatments**
  - LSP is pretty specific about what the rails are and the treatments that are allowed – be sure to get authorizations for different approaches.

Software

- Start early – it always takes longer than you think to do the software
- There are a number of basic CubeSat software programs available from NASA and commercial vendors – evaluate to see if one would work prior to starting from scratch.
- Consider using a real-time operating system (RTOS) for an additional level of safety. One option is FreeRTOS.

- Hardware watchdog timers can save your satellite if your software gets stuck in an infinite loop (caused by radiation damage or software error). Consider buying hardware with a watchdog and configure it to restart your flight computer in the event that tasks don't check in within a certain time period.
  - Primer by Jack Ganssle here: http://www.ganssle.com/watchdogs.htm
  - Solar events and South Atlantic Anomaly are huge factors in bits being flipped.

Software

- **Revision control is just as important for software.**

- **Use version control software, (github, bitbucket, etc), and establish team conventions for making commits to it. Software should have unit tests, and teams should use those tests before commits to ensure that changes made to one part of the software system do not negatively impact functionality elsewhere in the system.**
  - A CubeSat developer noted: we had some recurring problems with software engineers making small tweaks to things in the system so that their current project would work, and it would completely break what someone else was working on. This can be avoided (or at least minimized) by having a suite of software unit tests and requiring that those unit tests be used before making a commit to the version control software.

- **Put a software code version number in the telemetry data – that way you know what your system is running in case something is not functioning as expected.**

Sensors

- **Sensor Calibration is more than just getting the right units**
  - Understand your sensor calibration standards and NIST traceability.
  - Is the data they are reporting good data? Bad data leads to bad interpretations and conclusions.
  - Accelerometer calibration standards info for reference: https://www.nist.gov/calibrations/vibration-measurements-accelerometers-calibrations
  - Think about calibrations sooner rather than later – some take more time to have done which can impact schedule.

Other General thoughts

- **Don’t assume – check everything**
  - Example: We set up a test that was to use Nichrome wire to cut a restraint. It was set up exactly like a paper described, but it was drawing significantly more current than the paper said it should. After lots of troubleshooting the GSE cable harness was finally checked and it had more resistance than the test hardware itself. We just assumed it was good since it was provided as the test harness to use.

- **Tools – if you don’t know how to use something, ask.**
  - No one wants to break flight hardware because you were too embarrassed to ask how to use the tool.
  - And no one should expect you to know how to use all these tool.

- **Housekeeping**
  - Keep work area clean and free of FOD
  - Put tools and parts back where they belong

Post Assembly and Test

- **Don’t fiddle/test your spacecraft after environmental tests – it should be complete when it goes thru testing – one project broke system by doing post test software modifications and got pushed from their flight.**
- **If you need to service batteries, propulsion, etc at launch facility be sure you prearrange that with the Launch Provider**
  - Document how you plan to service and record the activites. Make sure to include who will be performing the work and ensure they are trained on your system.
- **Shipping – hand carry is recommended but make sure to have a letter from your school explaining what it is for TSA. Don’t unbox it unless you are ok with it. Your system might be sensitive to X-ray. Call TSA and brief them before showing up.**
  - Safe your system before traveling. De-energize electrical and pressure systems if possible.
  - Follow airline guidelines for carry-on/check baggage. Rules are changing and becoming more stringent. Check first.

Collecting Lessons Learned

- Lesson Learned is critical to making sure the same issues don't get repeated and solutions are identified and addressed for future work.
- Periodically ask your team to identify what worked, what didn't, and what could be done better and write them down to pass along to other team members as they join so that bad things don't keep happening.
- Continuous learning happens when you build CubeSats.

Deorbit plans

- **Have a plan to either deorbit or to get a ride that will limit your orbit time to match your mission timeline.**

Bottom line – Good Luck, have fun, and go learn something!!

References

Other References

- **Small Space Craft Body of Knowledge:**
  - https://www.nasa.gov/smallsat-institute/small-spacecraft-body-of-knowledge
- **CubeSat101 guide:**
  - https://www.nasa.gov/sites/default/files/atoms/files/nasa_csli_cubesat_101_508.pdf
- **CubeSat State of the Art Guide:**
  - https://sst-soa.arc.nasa.gov/
- **EEE parts –**
  - https://nepp.nasa.gov/index.cfm
- **Goddard Standards (location of GENERAL ENVIRONMENTAL VERIFICATION STANDARD (GEVS))**
  - http://standards.gsfc.nasa.gov
- **ARC STD 8070: Space Flight Systems Design and Enviromental Test**
  - https://www.nasa.gov/sites/default/files/atoms/files/std8070.1.pdf
- **LSP-REQ-317.01 RevB Launch Service Program: Program Level Dispenser and CubeSat Requirements Document**
- **Spectrum Guidance for NASA Small Satellite Missions.**
  - https://www.nasa.gov/sites/default/files/atoms/files/spectrum_guidance_smallsats_cubesats_2015.pdf
- **Quality control training classes: The AAQ (Academy of Aerospace Quality)**
  - https://aaq.auburn.edu/

Other References

- **Outgassing Material database for Space**
  - https://outgassing.nasa.gov/
- **NASA Standard for Workmanship on Polymeric Electronic Assemblies:**
  - NASA-STD-8739-1A
- **IPC Standard for accepting electric workmanship**
  - http://www.ipc.org/committee/drafts/7-31b_d_610F-draft-Feb2012.pdf
- **Electronics assembly guide handbook IPC-HDBK-001F**
  - https://ipc.kavi.com/higherlogic/ws/public/download/4721/IPC-HDBK-001F_Final%20Industry%20Review_Version%202_FINAL.pdf&wg_abbrev=5-22F
- **NIST:**
  - https://www.nist.gov/calibrations
- **SPOON**
  - https://spoonsite.com/openstorefront/login/index.html#/

Additional topics

- Orbital debris – materials not to use or be used judiciously
- Encryption
- Propulsion
- If flying GPS you are supposed to monitor for infiltrations/spoofing – need to find the document that says this is a requirement
- Removal of epoxy –
  - https://focenter.com/epoxy-removal-methods-and-strategies/
  - https://www.tedpella.com/technote_html/Reworking_Cured_Epoxy.pdf

- FCC licensing can take up to 18months (typically 12 months) so start this early.
- NOAA image licensing – if you take picture you need to look at this!
  - https://www.nesdis.noaa.gov/CRSRA/licenseHome.html

- Notify **CSpOC** when you get manifested – they track your satellite for you.
  - https://www.space-track.org/auth/login

- Batteries – ISS cert’d and charged
- Don’t try to load software on the first pass
- Cameras – there is additional clearances that you have to go thru and having shutter control would be helpful