Test and Integration Facilities

July 5th, 2023

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Agenda

- Hardware Protection
  - Why, when, and how
- Hardware protection breakdown
  - ESD
  - Clean Rooms
  - Procedures
  - Training
- Hardware Handling
- School Equipment Guidance
- Training References

Hardware Protection: Why it Matters

- Satellite components are sensitive
  - Electro-static discharge (static electricity) can jump from person to hardware, damaging it.
  - Many devices are sensitive to cleanliness
    - Lenses must be clear of particulates/oils
    - Conductive particles short circuits
    - Many materials can outgas then recondense on sensitive surfaces
- Failures can be latent
  - Satellite may pass ground testing only to fail on orbit as a result of mishandling on the ground weeks or months prior. Particularly ESD damage and outgassing.
  - Most satellites have one chance to work on orbit, there is no taking it back to the cleanroom to fix it

Hardware Protection: When to protect

- Protection starts the second a satellite part is delivered to your facility
  - Have a plan and documentation to receive and store hardware
  - Who will have access to the hardware?
- Treat all your hardware with care (like it could be flight)
  - If “flight hardware” is damaged or does not work correctly, EDU components might save a program if they can be swapped in for flight. Don’t risk losing this option by treating “non flight” components poorly
- Bad habits are hard to break
  - Practice good habits with “non flight” hardware. You may not have flight hardware now, but you will eventually
  - Mishandling is the cause of nearly all UNP hardware failures during testing
  - To bring your satellites to AFRL for Phase C environmental testing, they must meet AFRL standards

Hardware Protection: How

- ESD control
- Clean Rooms
- Procedures
- Training

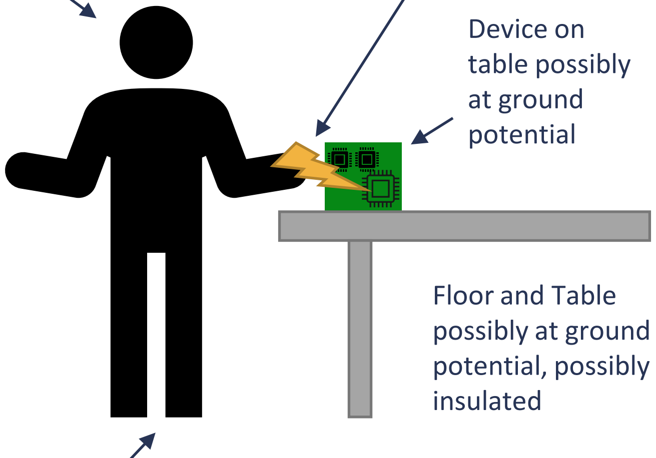

AFRL Image

Hardware Protection Breakdown: Electrostatic Discharge (ESD)

- Static electricity constantly builds on the human body.
  - Touching a surface at a different potential (voltage) results in a rapid energy discharge (a shock)
  - Shocks small enough to be imperceptible to humans can easily damage microchips and other sensitive electronics

Activity	10-25% Relative Humidity	65-90% Relative Humidity
Walking on Carpet	35000 Volts	1500 Volts
Walking on vinyl	12000 Volts	250 Volts
Working at bench	6000 Volts	700 Volts
Lifting a poly bag	20000 Volts	1200 Volts
Sitting in urethane foam chair	18000 Volts	1500 Volts

Source: Electrostatic Discharge Association



Hardware Protection Breakdown: Electrostatic Discharge (ESD) Cont.

- Setting up ESD area
  - Designated ESD working areas should be located away from traffic areas
  - This area should be clearly marked with signs and floor tape
  - A permanent area is highly recommended. Moving and disconnecting grounds can cause problems

Hardware Protection Breakdown: Electrostatic Discharge (ESD) Cont.

- ESD work area requirements
  - Working table with ESD dissipative mat
    - Tables should be metal, wood can be ok with mat, not plastics
    - Another working table should be next to the ESD table to store static generating materials like paper procedures
  - Wrist straps
    - Wrist straps must be worn within 3’ of ESDS devices
    - Wrist strap allows current to flow safely from personnel to ground
  - Common ground point
    - This can be electrical ground, may want a 1 MΩ resistor inline
    - Try and tie all grounds to one point
  - Dissipative floor mats can help
  - Avoid working with with ESD sensitive devices if humidity is below 30% or above ~70%
    - Humidity should be closely monitored
    - ESD storage should be near the ESD table
      - Open ESD storage is not recommended but will need to be grounded if used
      - ESD storage bins are best

Hardware Protection Breakdown: Electrostatic Discharge (ESD) Cont.

- Facility Considerations
  - Table, ESD mat, and wrist strap terminal should share ground point. This ground point should be wired to building ground with 1 MΩ between ground point and building ground. Avoid ground loops
  - Relative humidity must be between 30% and 70%. If humidity is below 30%, do not work on or near sensitive hardware. For extremely sensitive hardware, humidity must be between 40% and 70%.
    - Ensure humidity is at proper level at workstation, HEPA filters will reduce humidity of air passing through
  - ESD floor mats
  - ESD safe tools
  - Peeling away an old tacky mat layer creates ESD, ensure hardware is at safe distance and personnel are properly grounded after peeling

Hardware Protection Breakdown: Electrostatic Discharge (ESD) Cont.

Exploration Research and Technology Programs

Key to ESD protection: Keep everything at the same potential (ground)

Actual ground test meters for mats are very expensive. If only available tool is a multimeter, best practice is to test resistance from building ground point to farthest reaches of wires (not across mat).

ESD mat grounded to table ground point

Sensitive electronics sitting on ESD mat and grounded to table ground point

Banana plug wrist strap receptacle provides reliable grounding but can limit freedom of movement

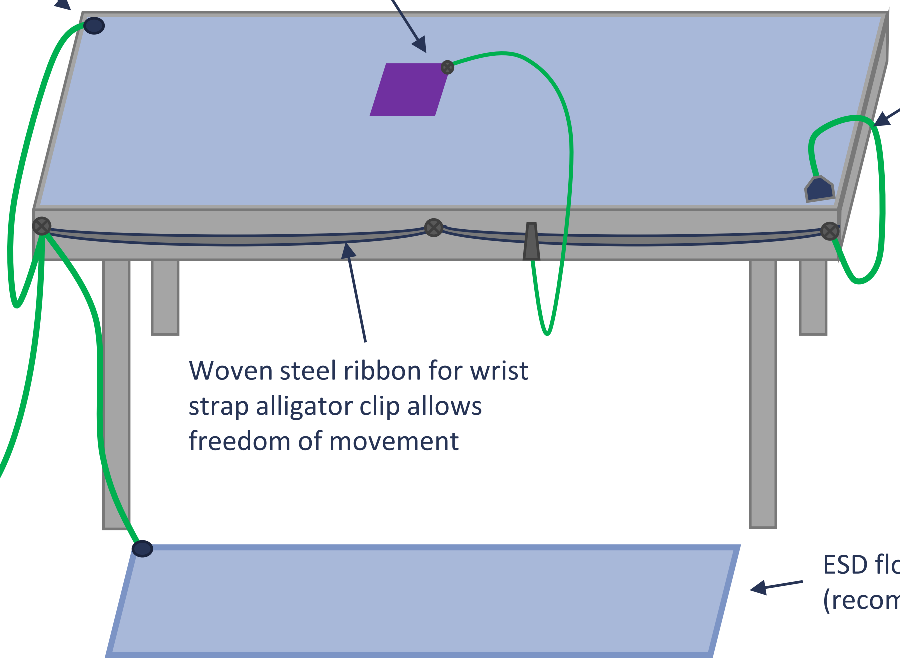


Table grounded to building ground. If building ground is not available, outlet frame ground can be used. A 1 MΩ resistor may need to be installed to protect hardware from voltage spike example lightning strike.

Woven steel ribbon for wrist strap alligator clip allows freedom of movement

ESD floor mat (recommended)

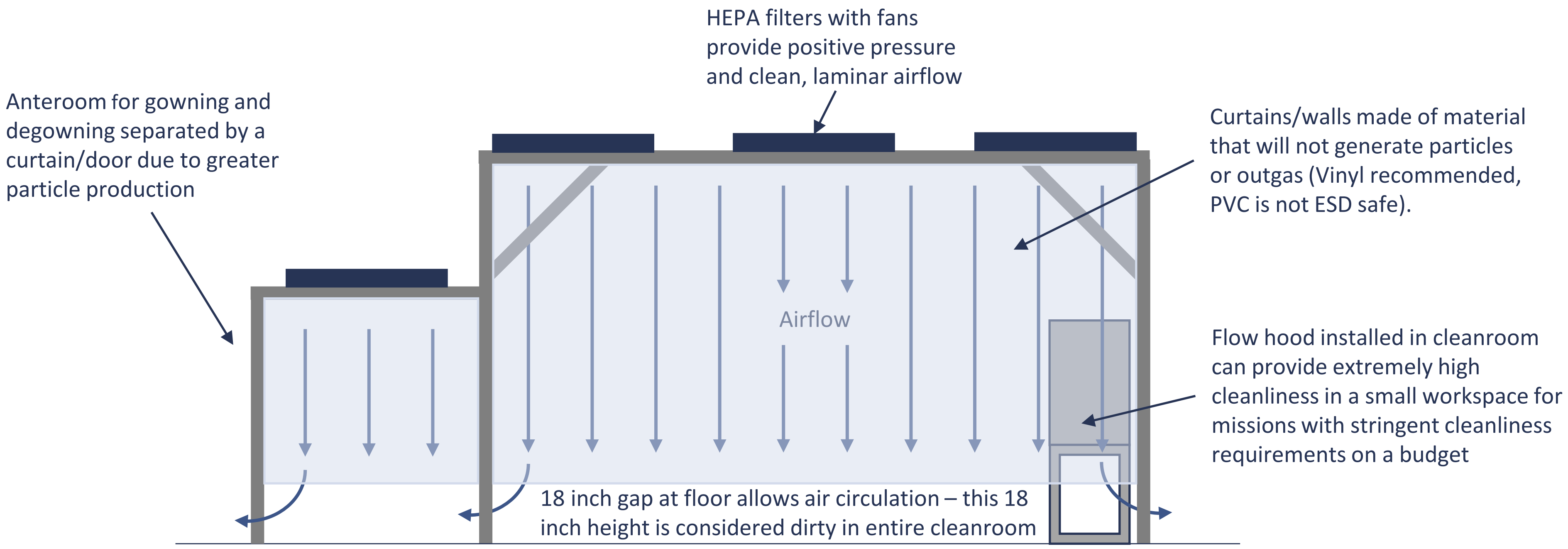
Hardware Protection Breakdown: Electrostatic Discharge (ESD) Cont.

- ESD Protection Practices
  - Prior to approaching ESD sensitive items:
    - Check relative humidity in work area
    - Gown up (smocks/frocks)
    - ESD wrist strap
      - Test any time it is put on
  - Place ESD storage and work areas away from high traffic areas
  - Clearly label ESD areas
    - Signs in area and tape on ground
  - Do not approach within 3 feet of hardware or tables and shelves holding ESD sensitive hardware unless properly equipped
  - Training for EVERYONE who has access to the ESD area

Hardware Protection Breakdown: Cleanrooms

Usually a standalone enclosure which allows ventilation control independent of building HVAC

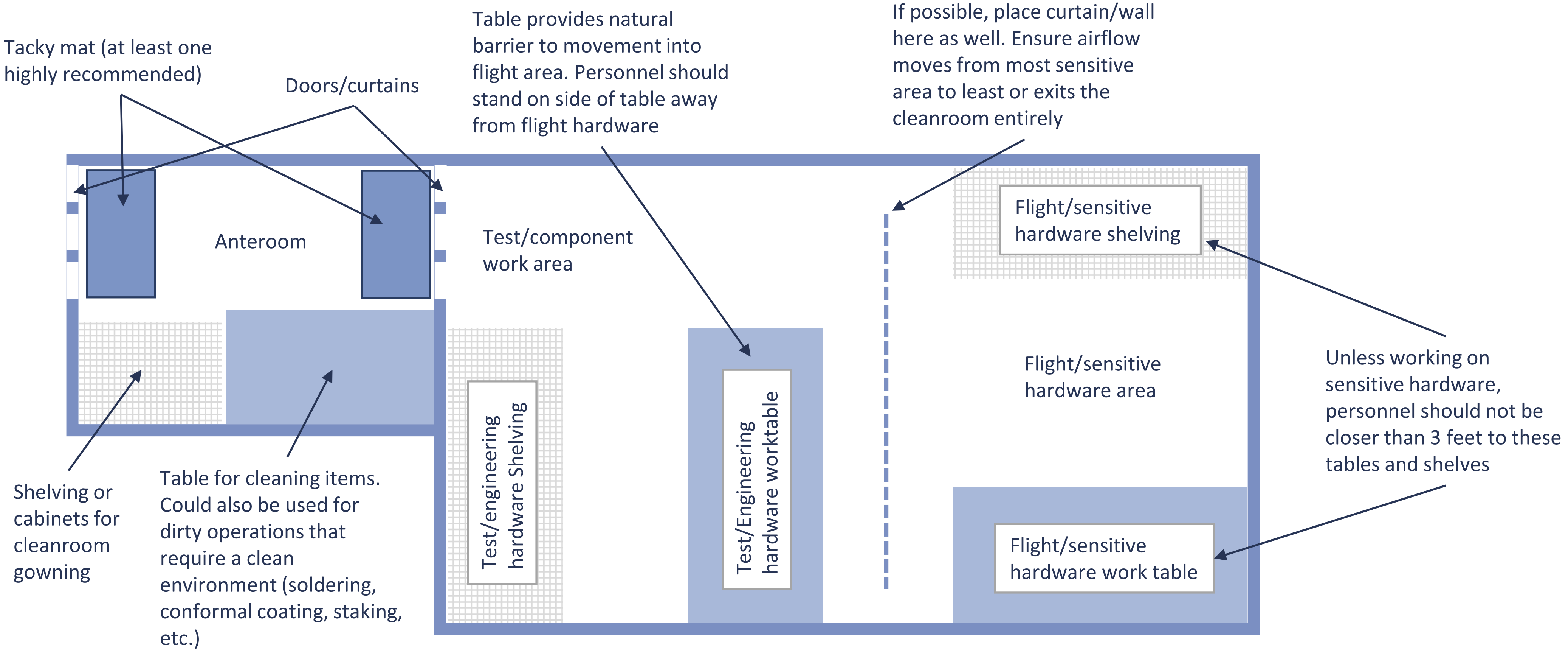
- Building HVAC should still supply clean, humidified air



Possible layout of a cleanroom

Hardware Protection Breakdown: Cleanrooms Cont.

This diagram shows general practices which should be followed, not a required layout. Note: The cleanest area does not have to be reserved for flight hardware early in the design cycle. Arrange hardware according to sensitivity needs of cleanest/most controlled to least clean/least controlled.



Hardware Protection Breakdown: Cleanrooms Cont.

- How are cleanrooms rated?
  - Fed STD 209E (Still used in government/space but somewhat outdated)
    - Number of .5 micron or larger particles per cubic foot of air
    - Most UNP schools use a class 10,000 (ISO 7) or 100,000 (ISO 8) cleanroom
  - ISO 1-9 (More current)
    - Maximum number of particles of various sizes
- Cleanrooms protect sensitive hardware from dust and contaminants
  - Airborne particulates
  - Airborne oil and grease
- Protect sensitive hardware from environment
  - Low humidity
  - Temperature
  - Light spectrum (depending on sensitivity of hardware)
- Protect sensitive hardware from people
  - Clumsiness
    - Provides physical barrier and mental barrier (people are more cognizant of proper practices inside a controlled environment)
  - Particulate generation
  - Finger oil

Hardware Protection Breakdown: Cleanrooms Cont.

Major sources of contamination

- People:
  - Skin flakes, dandruff, hair, fingerprints, spit, etc.
- Activities:
  - Machining, cleaning, packaging, soldering, testing, etc.
- Environment:
  - Dust, fumes, vapor, fungi, bacteria, pollen, bugs, etc.
- Offgassing:
  - Hydraulic presses, solvents, paints, tools with grease or polymeric parts
- Flaking/Shedding:
  - Wood, paper, packing foam, non-lint-free wipes

Hardware Protection Breakdown: Cleanrooms Cont.

- When entering and exiting a clean room, the following steps should be taken:
  - Clean shoes on tacky mat
  - Leave personal items in anteroom
  - Gown from top to bottom with gloves last:
    - Hair net
    - Beard net (if applicable)
    - Frock (Bunny suit if class 1000 and cleaner). Embedded ESD fibers break down over time. Ensure ESD frocks and clean frocks are not too old – contact manufacturer.
    - ESD strap (test grounding)
    - Booties if class 1000 and cleaner
    - Powder-free gloves
      - For very sensitive items or extra cleanliness, put on two pairs of gloves as the first step. Continue through the list of steps and at the end remove the outer pair of gloves. This ensures that the process of gowning is not contaminating the gloves which are used to handle hardware.
  - Always use new gloves, hairnet, and beard net when entering cleanroom
  - Ensure non-disposable garb is clean before use. Smocks should be laundered after multiple normal uses or any single use outside the cleanroom
    - To launder smocks, either run them with only water, or run them twice, the second time using only water
  - Thoroughly clean any items brought into the cleanroom

Hardware Protection Breakdown: Cleanrooms Cont.

Mask and/or beard net

Gloves

Bouffant

Frock

Hardware Protection Breakdown: Cleanrooms Cont.

- Bringing items into cleanroom
  - Thoroughly wipe all surfaces with 99.9% Isopropyl Alcohol (IPA) and lint-free wipes
    - Clean from the top down
    - For very dirty or greasy items such as machined parts, a pre-cleaning with simple green or Liquinox and de-ionized water is recommended
    - Machined holes or other hard to reach places should be cleaned with cotton swabs and IPA
  - Fasteners and small items should be soaked in IPA for at least 2 minutes
    - Pre-cleaning using an ultrasonic cleaner in de-ionized water and Liquinox recommended
  - Items brought into the clean room in containers should have the container wiped down before entry
    - Upon removal from the container, clean the item thoroughly
    - Remove the container from the clean room as soon as possible
  - Note: Do not clean ESD mats with IPA. IPA will break down the mats, use ESD mat cleaner

Hardware Protection Breakdown: Procedures

- Procedures are a necessary part of the assembly process
  - Documents necessary steps were performed for launch provider (Record of outcome)
  - Gives other team members a guide to follow
  - Protects hardware from mishandling
  - Sets scope (keeps team focused)
- Using short simple procedures for day-to-day operations. Example: gowning into a cleanroom. Have a one-page procedure posted when entering, have pictures and not a lot of words
- Making procedures for assembly and testing helps think through what needs to be done
  - Write procedures as if you will not be the one performing the work
    - Know your team. Some procedures may require a level of qualified personnel to perform the task
  - Have someone else read through them
  - Red lining procedures is perfectly acceptable
- It is easy to make 100-page procedures, Don’t.
  - When you can break the procedure into smaller ones, do

Hardware Protection Breakdown: Procedures Cont.

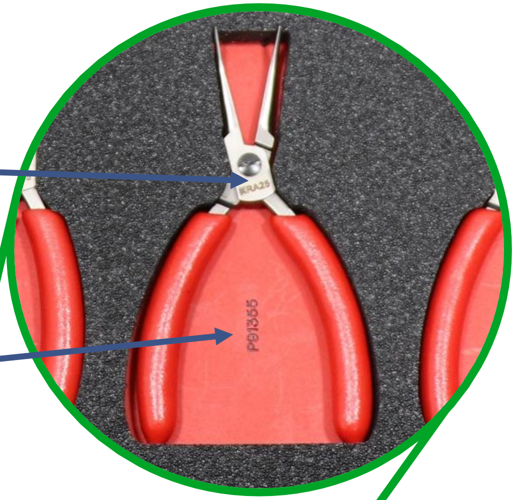
- Documenting the procedures
  - How does your team function?
    - Printed procedure
    - Electronic copies
    - Procedures can be tailored to be more efficient for your team
  - Completing procedure
    - Some procedures will only be run once, others could be used a few times
      - Consider making an as run document that could be marked instead of the procedure itself

Hardware Protection Breakdown: Procedures Cont. Tool Control

- Shadowboxing
  - Ensures all tools are put away in proper location
  - Makes missing tools obvious
    - Perform end of day checks to verify tools are in place
    - Less applicable to small satellites since tools won't get lost inside as easily, but ensures tool FOD is noticeable
  - Can be done manually with foam kits, laser cutting not required
- More stringent tool control schemes if necessary (likely not needed by UNP teams)
  - Signing tools in/out
  - Limiting access to locked toolboxes

Toolbox number engraved on part in case multiple identical boxes exist. Can also use colors or other markings

Tool part number ensures correct tool can be located if tool shadow is generic or a replacement tool is needed



AFRL Images

Hardware Protection Breakdown: Training

- Training is extremely important when dealing with sensitive spacecraft components
  - Team members must be trained to enter controlled areas
    - This could be an in-house created training or one that is nationally recognized (OSHA, NASA, etc.)
  - Keep a training log of who is trained for what
  - Trainings do not need to be long or complex
    - “The safety glasses go over your eyes, now you try them on. Great, use these when soldering” Training complete.
  - Not everyone may be qualified to be trained on everything, that is ok
    - You might only want a select few to be able to power on the spacecraft. Make this very clear and if the processes change to turn it on, retrain those that need it.
  - Training promotes proper culture and habits
  - Don’t train to check the box
    - Make it personable and relevant
    - Hands on training is always better that slides or email

Hardware Handling

- Flight Hardware (Good practice for engineering hardware as well)
  - Must have unique identification number
    - Each structural piece or board must be uniquely trackable
    - Fasteners can be tracked by type
  - Handling must be tracked at all times via logbook (not a comprehensive list):
    - Operations/testing performed
      - Test procedures should also record part identifier
    - Connector mates/de-mates
    - Locking helicoil uses
    - Machining modifications
    - Battery state of charge before and after storage
  - Must follow two-person rule
    - Quality assurance (signing forms and watching operations)
    - Extra hands
    - Sanity check
  - Must follow procedure
    - Do not touch flight hardware without a reviewed and approved procedure in place
    - If procedure is not followed exactly, thoroughly document why
      - Save all as-run procedures

School Equipment Guidance

hoangsame.com

safran-group.com

www.siglenteu.com

Facilities, equipment, and tools are not cheap. What can you do on a budget to meet the requirements?

School Equipment Guidance Cont.

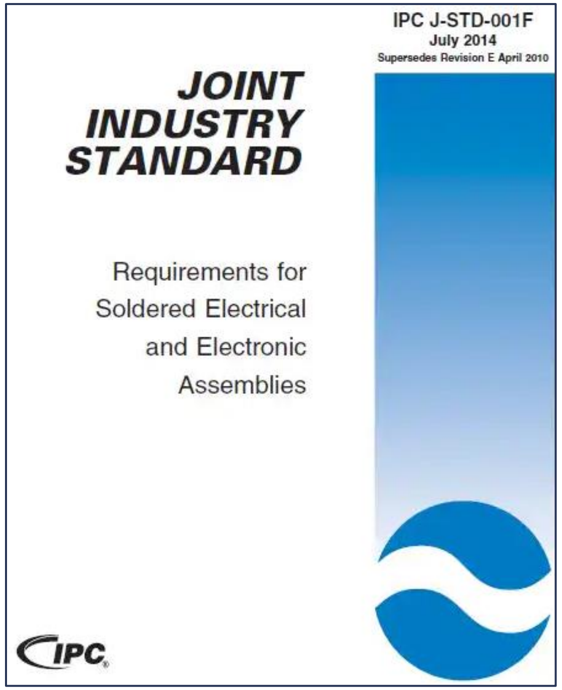
- Spend money where it matters
  - Safety (not a comprehensive list):
    - Soldering fume extractor
    - Safety glasses
  - Proper ESD protection
    - Mats
    - Grounding
    - Wrist straps and testers
  - Soldering iron
    - Recommend Metcal CV-5210 or similar

metcal.com

School Equipment Guidance Cont.

- Cleanroom COTS Kits
  - Structure typically powder-coated metal with vinyl curtains or solid acrylic sheeting, polycarbonate is not ESD safe.
- Cleanroom DIY Considerations
  - Extensive resources online:
    - One example: (https://www.gotopac.com/art-cr-cleanroom-design-10-steps)
  - Ensure adequate workspace
    - UNP recommends minimum of two 8-ft tables plus shelving in clean area, 1 6-ft table and shelving in anteroom
    - Tables exterior to cleanroom with wire pass-throughs allow software work without entering
  - Consider flow hood for sensitive parts – allows main room to meet lower standards
  - Ensure adequate humidification
    - Facility HVAC may circulate very dry air
  - Ensure adequate lighting
  - HEPA filter units will likely be most expensive part
    - Minimize volume to minimize number of filters required
    - See slide 8 for rough estimate of HEPA filters required. Filter requirements also consider volume airflow, not only ceiling coverage
  - Structures made of wood must be covered to avoid ESD and particle shedding
    - Mylar ESD film
    - Kapton Tape (acrylic adhesive, not silicone due to outgasssing)
  - Consider facility HVAC system and airflow to ensure proper circulation

Reference Materials

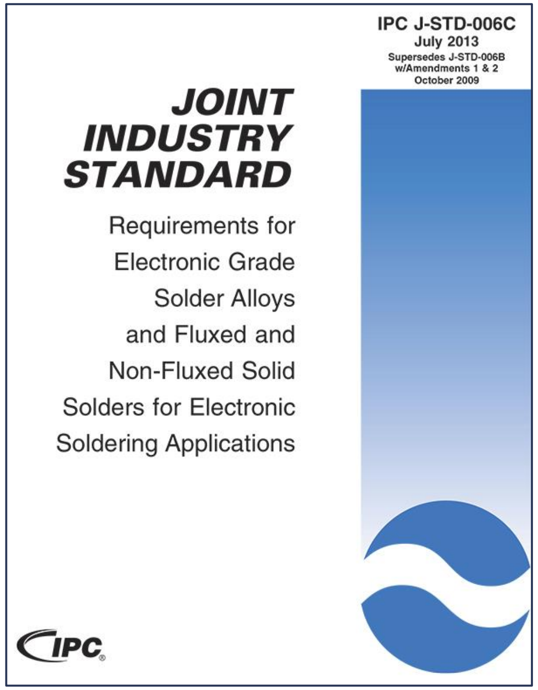


IPC J-STD-001F
July 2014
Supersedes Revision E April 2010

JOINT INDUSTRY STANDARD

Requirements for Soldered Electrical and Electronic Assemblies

IPC



IPC J-STD-006C
July 2013
Supersedes J-STD-006B w/Amendments 1 & 2 October 2009

JOINT INDUSTRY STANDARD

Requirements for Electronic Grade Solder Alloys and Fluxed and Non-Fluxed Solid Solders for Electronic Soldering Applications

IPC

Soldering Guidelines & Requirements

IPC J-STD-001: Requirements for Soldered Electrical Assemblies

Only available via purchase on IPC website (~$150)

Current Industry Standard

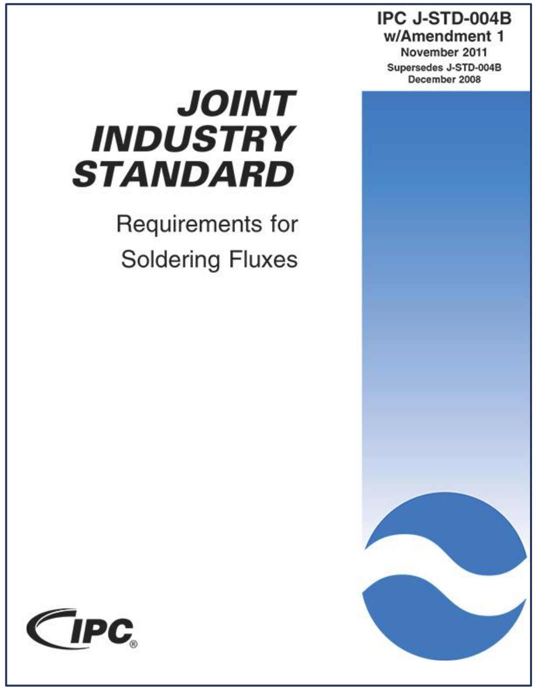
What solder to use

IPC J-STD-006: Requirements for Solder Alloys

Free and available through a quick Google Search

Current Industry Standard

Reference Materials Cont.

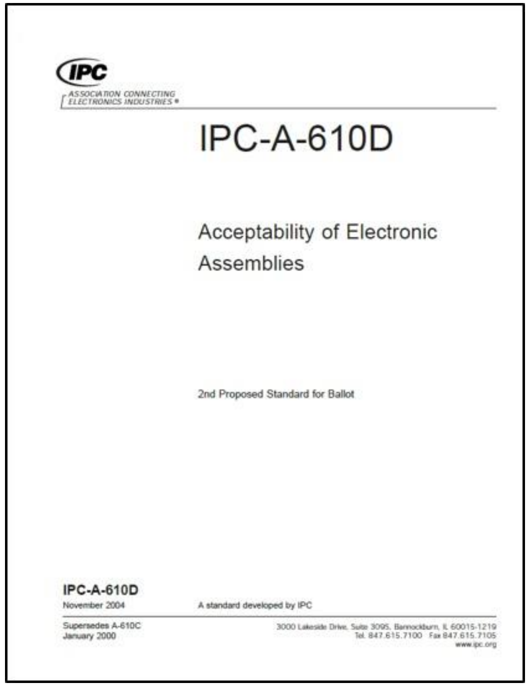


What flux to use

IPC J-STD-004: Requirements for Soldering Flux

Free and available through a quick Google Search

Current Industry Standard



How to inspect and verify a good solder joint

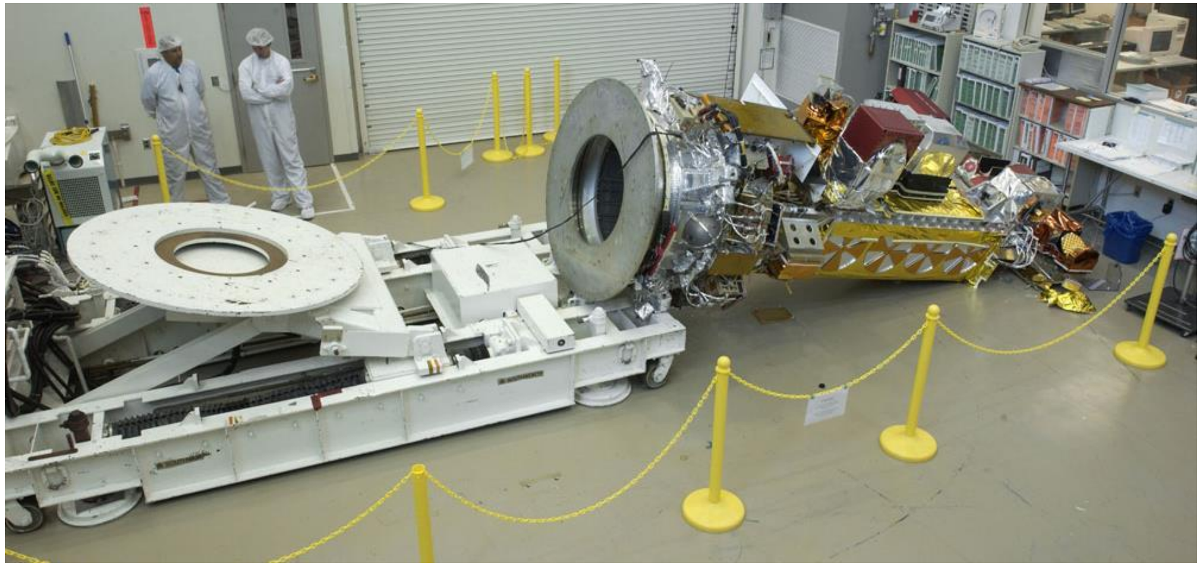
IPC-A-610

Free and available through a quick Google Search

Previous Industry Standard – Still Relevant & Utilized for training

Takeaways

- ESD protection is paramount
  - Many UNP and other satellites have been killed due to ESD
- Processes and procedures are vital to cleanliness, not just facilities
  - Watch cross contamination
- If you’re not sure how sensitive something is to cleanliness/ESD, determine the answer or treat it as sensitive.
- Promote a culture of learning from mistakes, not hiding them



wikipedia.org

Poor culture led to a failure to follow procedures and document hardware handling, causing $135 million worth of damage to NOAA-19

Questions?