

UNIP



Assembly, Integration,
and Test, Ground
Support Equipment,
and Environmental
Testing

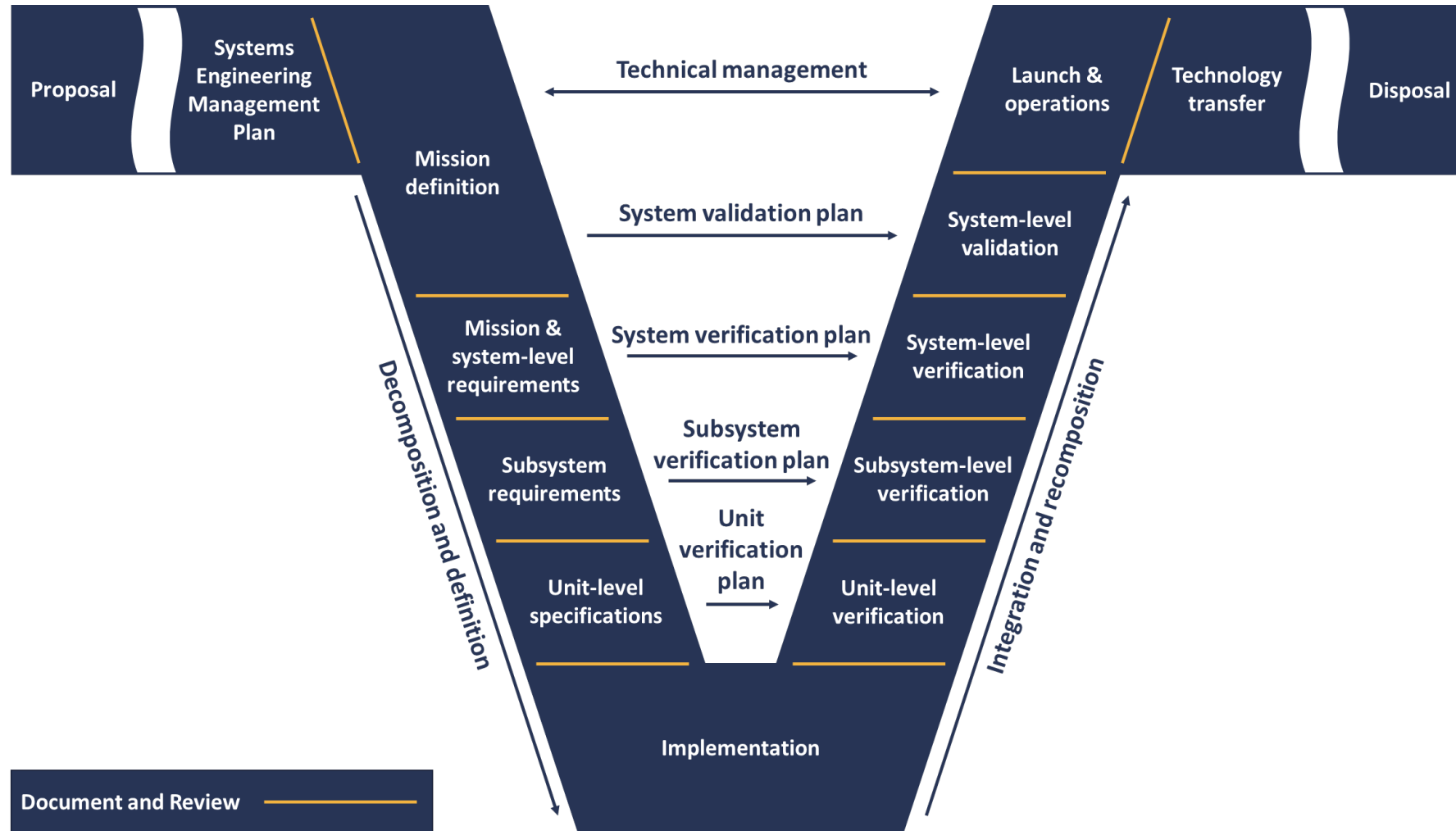


Exploration Research and
Technology Programs





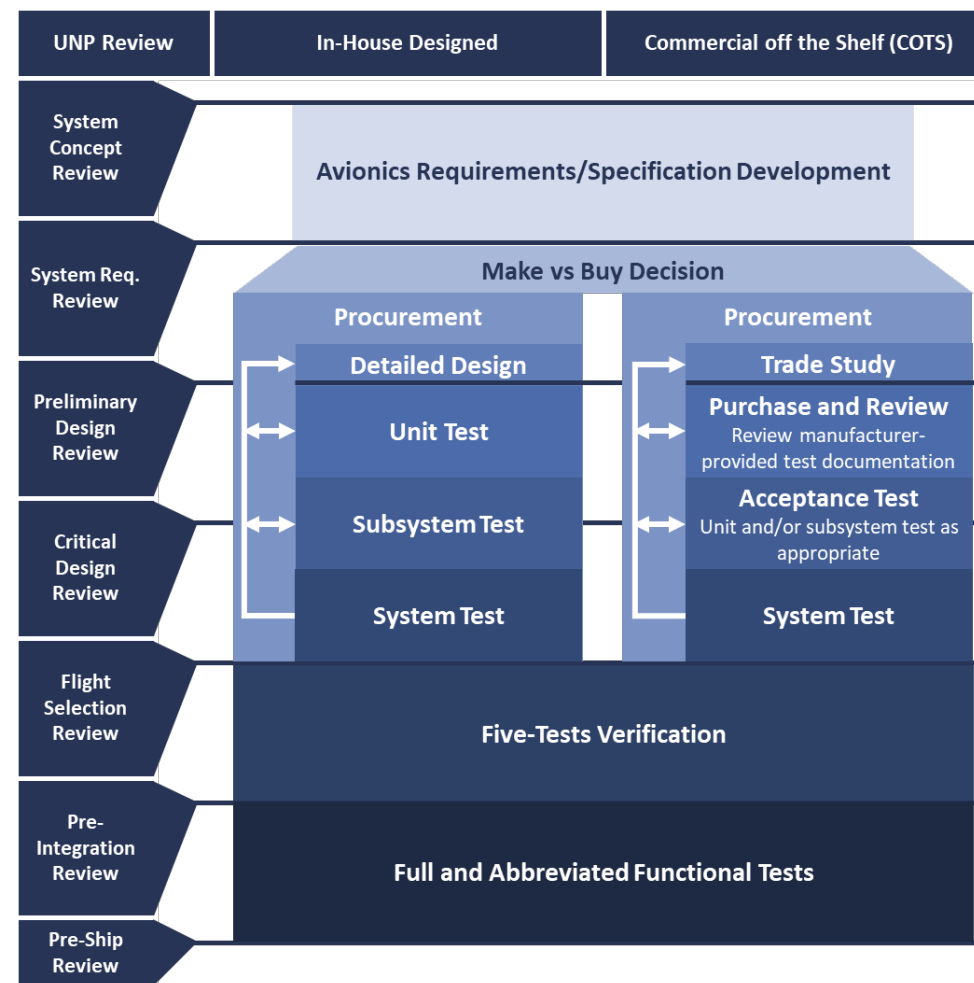
Assembly, Integration and Test



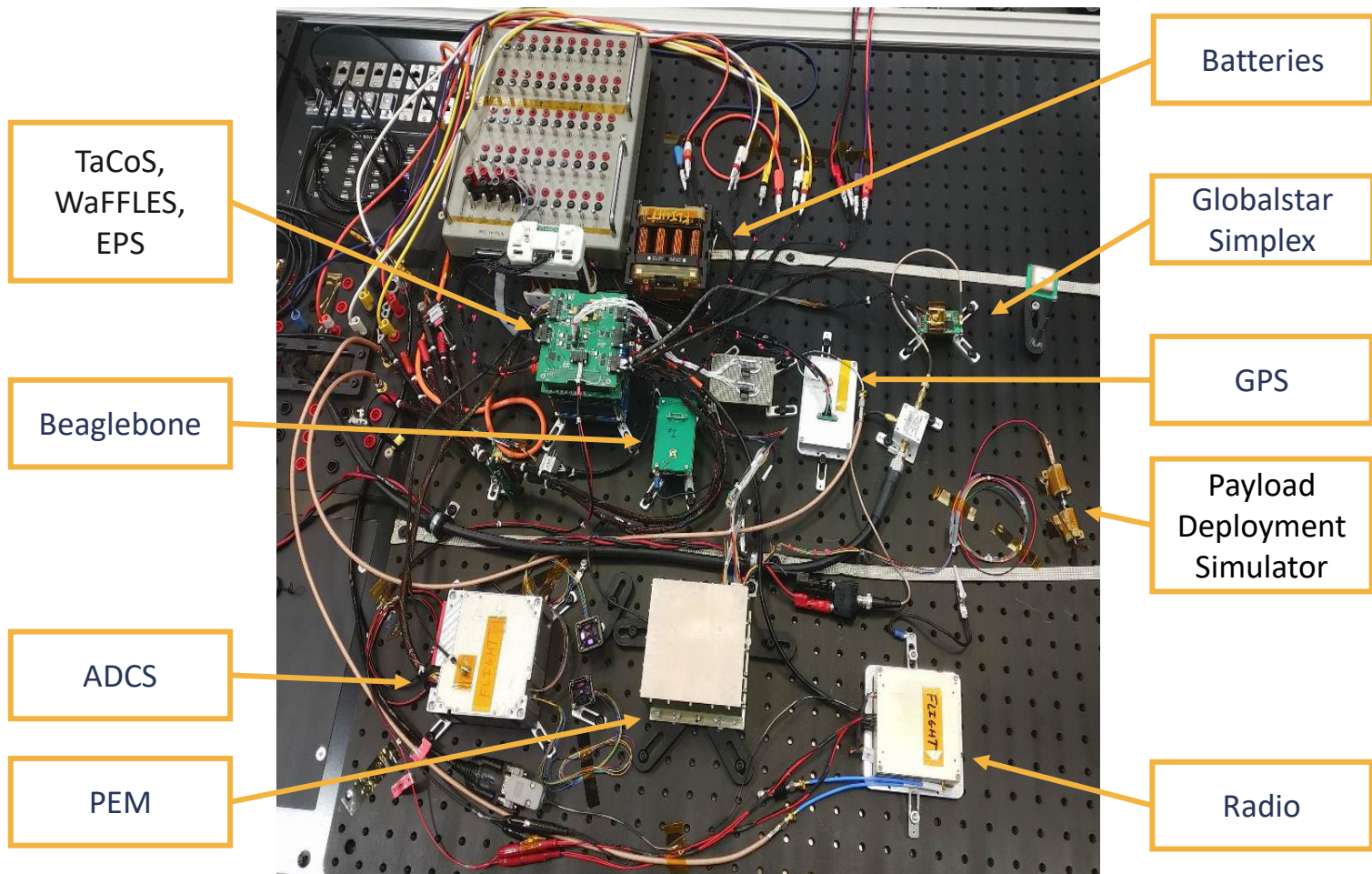
UNP What is “AI&T”?



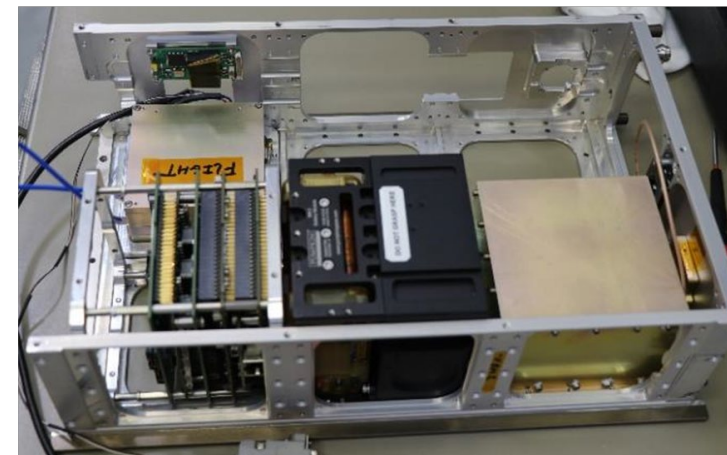
- A continuous, iterative process of turning low level components into the system of hardware, software and ground tools that meet your mission
- Teaching the engineering team to understand the system they’ve built
 - It does exactly what it was designed to do, now figure out what that was...
- Verifying mechanical, electrical, data and software interfaces
 - Does it fit?
 - Does it talk?
 - Is it on?



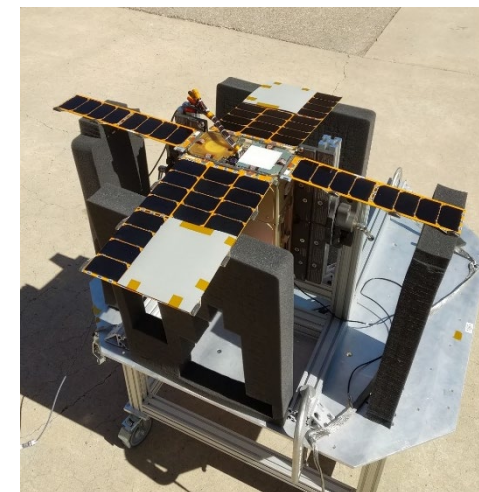
UNP Example: VPM



AFRL Image



AFRL Image



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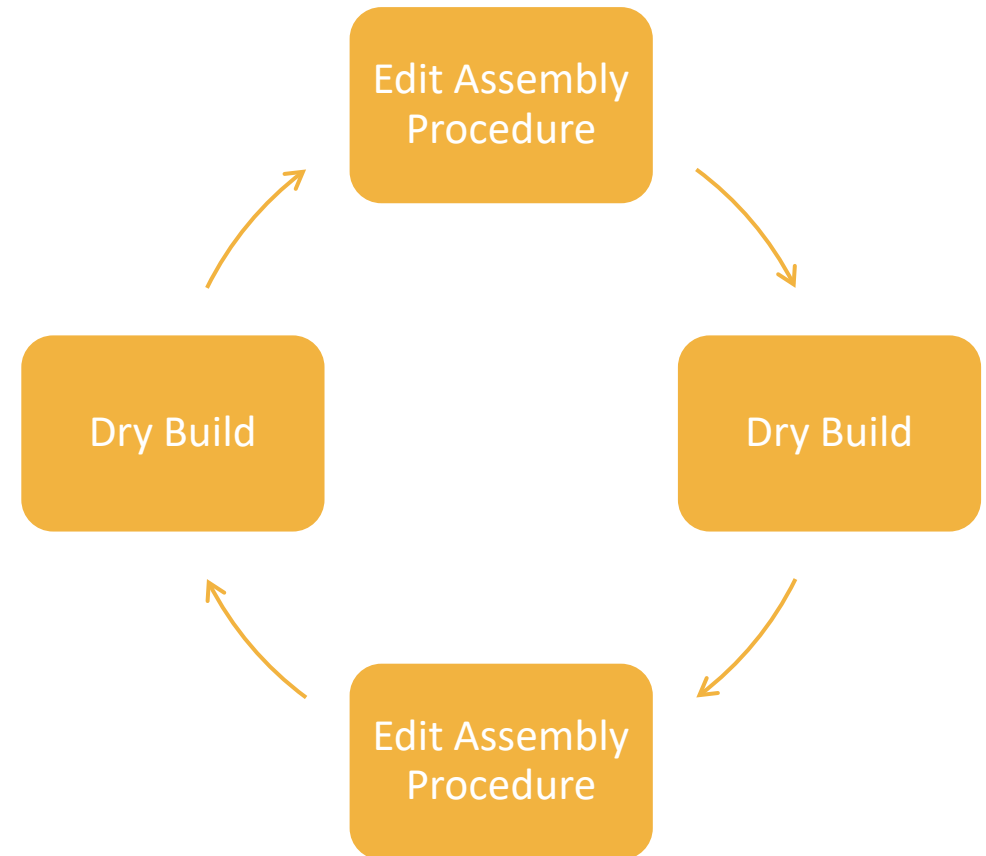


Assembly


UNP Assembly Tips and Tricks



- If Nothing Else: Design for assembly AND disassembly
 - What goes in will come out
- Do all CAD with the procedure in mind
- Remember to account for tool access
 - A bolt you can't torque is as good as the hole it falls out of
- Plan for connectors, harnesses and accessibility



- Think Lego
- Kit all fasteners, connectors, harnesses, etc.
- Include pictures, arrows, notes, etc.
- Show designers intent
- Don't over specify; leave room for the assembler to interpret and execute



STEP 2: Attach Section Connector

Fasteners:

- 4: #4-40 x 1.375" Pan Head
- 4: #4-40 x 0.3125" Standoff
- 4: #4-40 x 0.625" Unthreaded Spacer

The Kesler subassembly is mounted to the section connector via 4 #4-40 bolts. Install the Kesler subassembly as shown to the left.

Apply a very light amount of staking compound to the inside threads of each standoff prior to installation.

Torque bolts to 6.125 in-lbs.

Stake each bolt head as it is torqued.

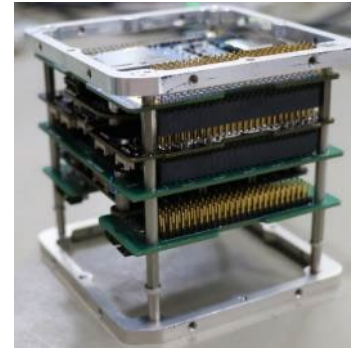
Bolt #	Running torque	Final torque	Tech	Q/A
1				
2				
3				
4				

While applying the required torques, record the bolt numbers on the diagram to the left.

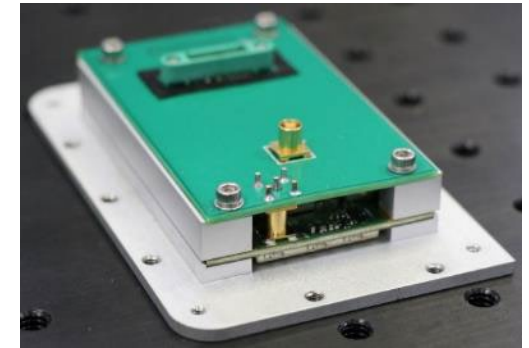
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Image Courtesy of University of Texas at Austin

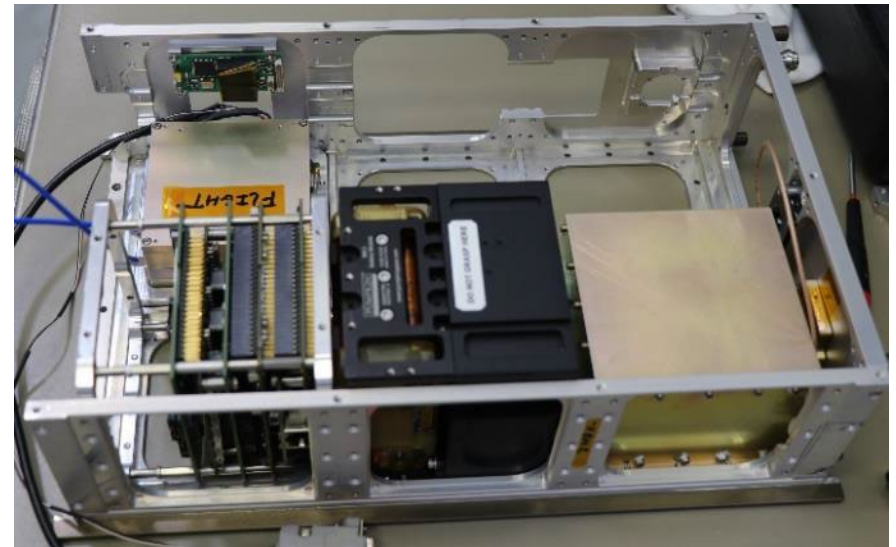
- Initial Assembly
 - Assembled avionics stack
 - Assembled subsystems and panels
 - Subsystems integrated to structure
 - Optimal assembly order determined
 - Harness lengths measured in place
- Next Steps
 - Revise Draft Assembly Procedure
 - Fit check flight harnesses
 - Secure components for vibration
 - Full build for flight testing



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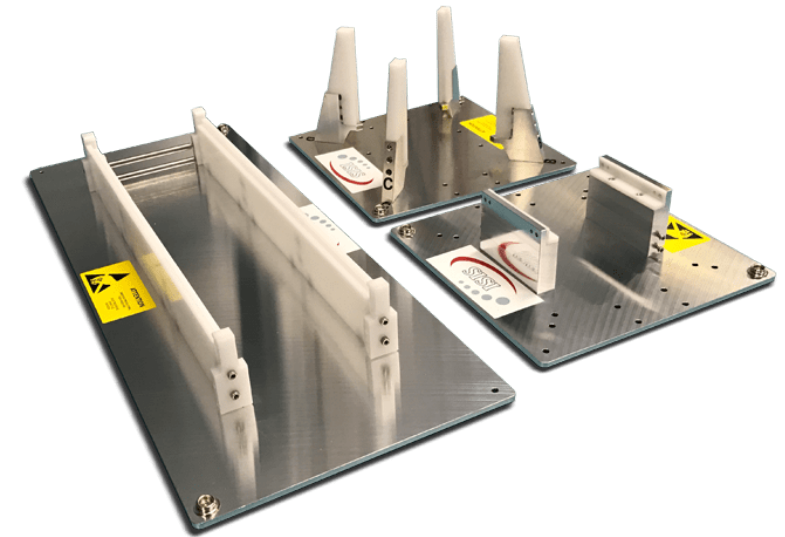
Exploration Research and
Technology Programs

Ground Support Equipment (GSE)

UNP GSE and Why It Matters



- Ground Support Equipment (GSE) is non-flight equipment used during integration and testing activities
- Two general types of GSE
 - Mechanical GSE (MGSE)
 - Electrical GSE (EGSE)
- The GSE is not usually a single item
 - Integration stands shown are all MGSE for the same mission
- Benefits of designing/developing the proper GSE
 - Saves time during integration and testing activities
 - Protects flight hardware from damage or mishandling
 - Prevents improper connections



www.isispace.nl



MGSE

Mechanical Ground Support Equipment

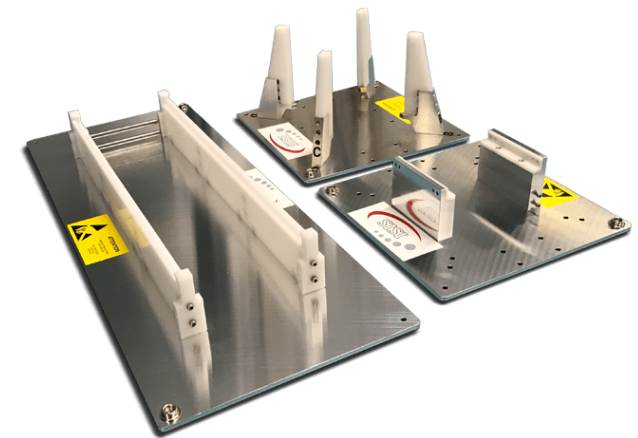
UNP Integration Stand(s)



- Integration stands support the vehicle and subassemblies during integration
- When designing an integration stand, keep in mind
 - Access in multiple orientations
 - Secure restraint to prevent shifting or falling
 - Potential inhibit features
 - When the stand will be utilized
 - Electrical grounding
 - Harness support
- Simple rail supports can be utilized for most CubeSats

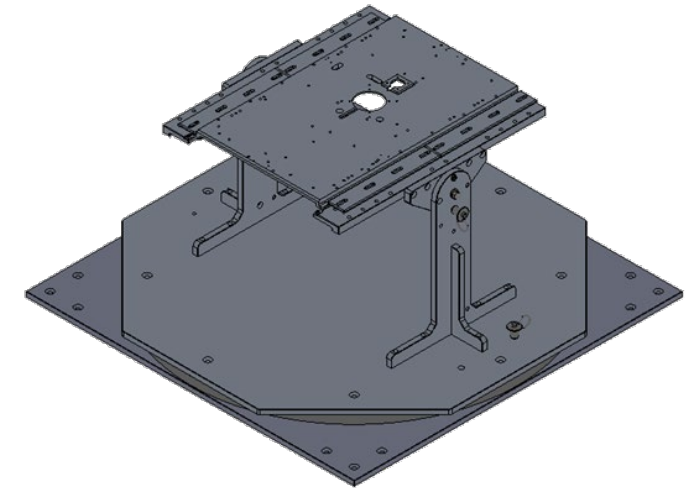


www.nasa.gov/feature/jpl/nasa-activates-deep-space-atomic-clock



www.isispace.nl

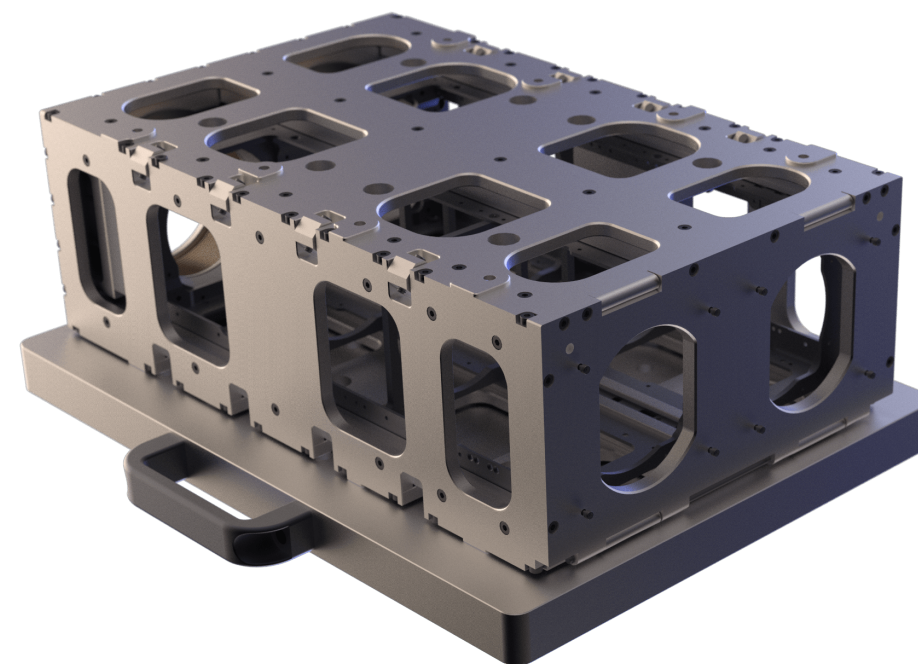
- While less of a concern for traditional CubeSats (1U-3U), when the vehicle becomes larger, handling needs to be considered
 - You may be able to manipulate smaller CubeSats by hand, but larger CubeSats (i.e., 12U) may require the attachment of fixtures such as handles to manipulate
- Interface points can provide positive contact with the vehicle while protecting delicate components such as solar panels
- Example: turnover fixture
 - Doubles as integration stand
 - Allows vehicle to be rotated about one or more axes
 - May not be necessary for smaller CubeSats



AFRL Image

Integration and turnover fixture
designed for CubeSats

- During testing many different setups will be used
- Testing interfaces may be required for
 - Vibration Testing
 - Thermal Vacuum Testing
 - CG/MOI Testing
 - COM Testing
 - Deployment Testing
- For each of these tests, consider
 - Access required
 - Specialized restraints/supports
 - Activation state of the vehicle



endurosat.com/cubesat-store/ground-support-equipment/6u-test-pod/

Vibration test deployer

UNP CubeSat Protection and Shipping



- Protective Covers/RBF Covers
 - Protect sensitive hardware before final flight integration
 - When designing covers consider
 - What is being protected
 - When and how the cover will be removed
 - Access constraints imposed by the covers
 - Most RBF Covers are red or have red tags attached to visually identify that they are not flight hardware and must be removed
- Shipping Containers
 - Shipping should be considered early
 - For small vehicles - properly padded Pelican Cases often used
 - When designing a shipping container leave room for Shock Watches or Shock Sensors to determine if something happened during travel



blogs.esa.int/eolaunches/2018/07/19/aeolus-remove-before-flight/



EGSE

Electrical Ground Support Equipment

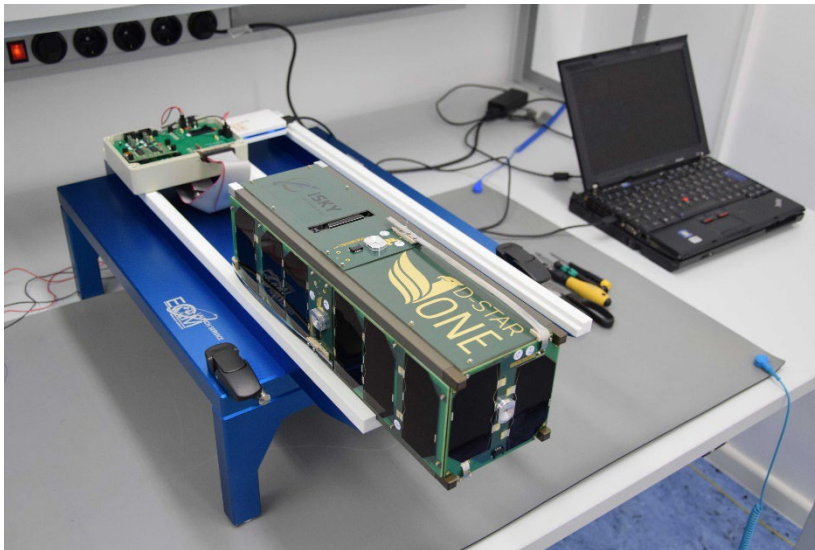
UNP What is EGSE?



www.clemessy.ch/egse/

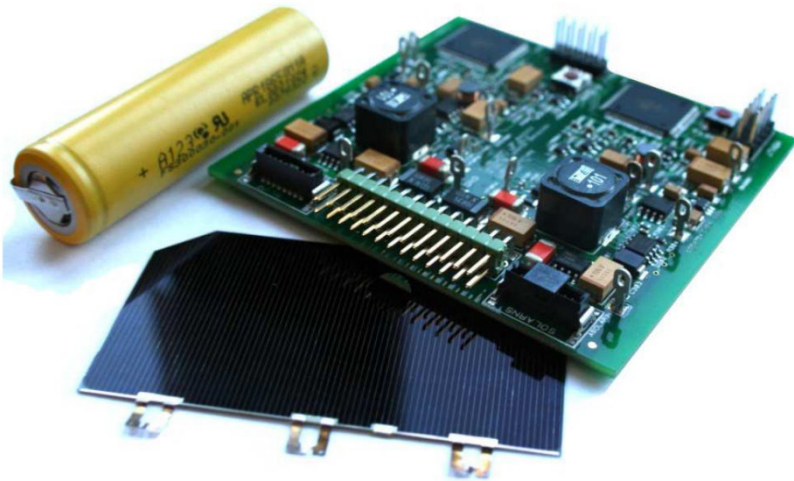
- Allows interfacing with and testing of integrated satellite
- EGSE is mission specific but commonly includes
 - Power supplies
 - Multimeters
 - Signal Generators
 - Ground Radios
 - Network Equipment
 - Laptop
 - Switching and data collection systems
 - Cabling to connect to spacecraft
- Ensure equipment is properly set up and configured before connecting to flight hardware

- Satellite must have dedicated EGSE port
- Communication directly over bus communication lines via EGSE port provides easy access for ground testing
- This connection is non-flight representative but allows significant insight during testing



www.nanosats.eu/org/german-orbital-systems

- Designing a proper charging system can be a significant effort
- Some things to consider
 - Hardware limitations for charging current and voltage
 - Harness current and voltage limitations
 - Charging time required
 - Direct powered operation (battery bypass)



mr-fahrenheit.com/communication/

DO NOT leave batteries charging unattended

- Near the end of integration and testing, over-the-air communications testing should be performed
- These tests have some additional EGSE requirements
- Things to consider
 - Does your license allow for free over-the-air transmission testing?
 - Use of RF Hats or RF Chambers
 - How does distance affect your testing?
- This will be the most representative test of your on-orbit communications due to actual data rates and symbol errors



www.isispace.nl/product/isis-cubesat-development-platform/



Integration

1. Assess the board, subsystem or component at the lowest level possible

- More complexity = more variables = more confusion
- Write, check, and execute a component-level full functional test
- Verify interfaces, performance metrics, power and data
- Support interfaces (serial cable, power supply) change behavior
- Measure, weigh and photograph every item

2. Build the flatsat piece-by-piece, check at every step

- Flatsat tests power, data and software are compatible
- Execute a procedure for each step
- Check connectors are SAFE to mate
- Start writing software interface as early as possible

3. Execute system-level tests on the flatsat as many times as possible

- No test is one-and-done; your system needs to work continuously, in space, for a year or more.
- All time spent on hardware builds experience, knowledge and ownership
- The five tests are to validate what must work
- Use the system, learn its quirks

4. Repeat 1-3 with flight hardware

- Re-execute the procedural processes you built with your Engineering Model (EM) and flatsat
- EM hardware is always different
- Datasheets and ICD's are helpful suggestions towards designers' intent
- Be careful: human error is by far the leading cause of AI&T failures
- Flight hardware = failure reports and reviews

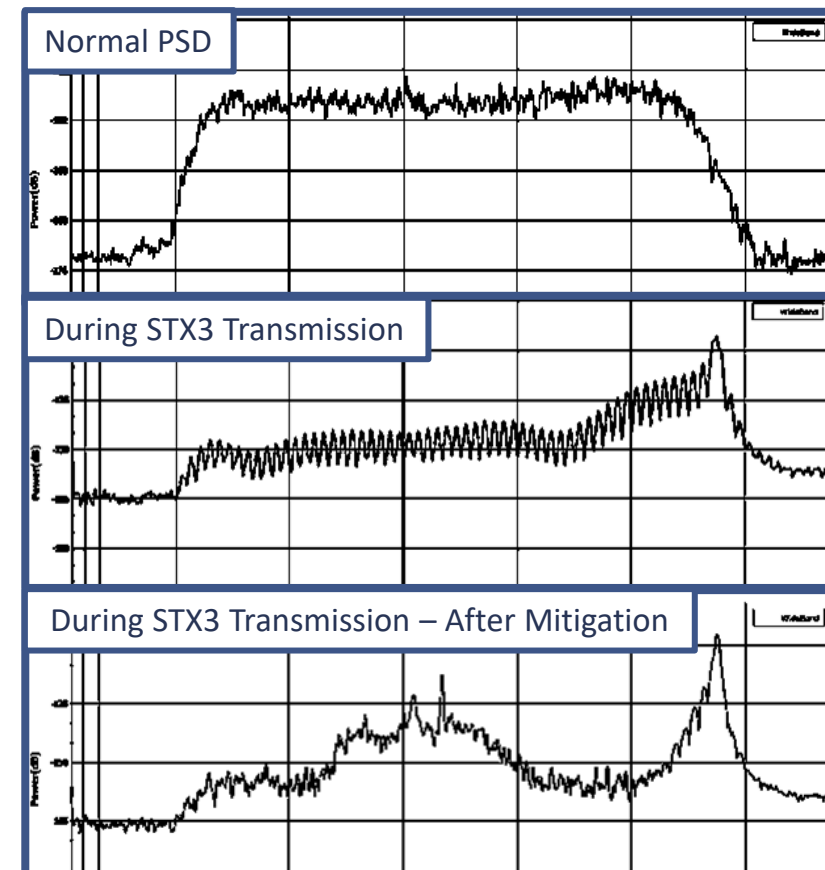
5. Assemble!

Write down what you learn; you're not the only one who needs to know

UNP Example: GPS Interface



- Problem
 - GlobalStar STX3 Modem (L-Band transmitter) and Novatel OEM719 (GPS L-Band receiver) interfere dramatically
 - Every time VPM broadcasts its GPS position, it loses GPS position..
 - Electromagnetic Interference/Compatibility (EMI/EMC) issue
 - Two systems that perform as required on their own impact one another when together
 - Normal integration activities uncovered this issue
 - Correlation in activity and behavior is the primary goal of the integration team
- Mitigation attempts
 - Moving G* and GPS antennas farther apart → no effect
 - Putting NovAtel in metal box → mixed results, initial testing promising but further testing showed loss of lock
 - Inline SAW filter on GPS antenna → receiver retained tracking on all satellites with small dip in carrier to noise ratio
- Final implementation
 - NovAtel in metal box
 - New Tallysman GPS antenna with narrow integrated SAW filter
 - Novatel Interference Toolkit HDR mode and software BPF enabled



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UNP Integration: Software



- Software tools are more critical to successful integration than a functioning circuit board
- Scripting can alleviate some human error
 - If you have to do it more than twice, consider making Python do it instead
 - Logging = record keeping = Happy UNP Office
- Software is not a replacement for thinking
 - You still need to understand the system
- Use what you know, Google what you don't
 - The maker community is incredible at this, use it (in accordance with all legally binding license agreements – do not simply steal code)



Integrated Testing

Primary Reference: UNP NS-11 Users Guide



- Simulated/Long Range Comms (SCT) (validate link)
 - Can you talk to your spacecraft's radio when it's integrated into the spacecraft (and vice versa)?
 - Contributes to understanding/checking of link budget values
- Command Execution (CET) (validate software)
 - Does all your on-the-ground and on-satellite software (including non-nominal commands) work as intended?
- ADCS Verification (validate pointing, if applicable)
 - Can your spacecraft point correctly and send correct data to other subsystems?
- Charge Cycle (validate power)
 - Do your batteries and solar panels function as intended?
 - Includes demonstration of satellite automatically entering safe mode when depth of discharge is met, input power rejection when full capacity
- Day in the Life (DitL) (validate system operation over long duration)
 - Validate system in nominal operation (simulates functionality of satellite from launch to end-of-life)
 - Long test (at least 24 hours, simulate 1-2 weeks of satellite life per day of testing)

UNP Other Integrated Tests



- Full Functional Test
 - Checks functionality of every subsystem as best as possible when integrated
 - Makes sure vehicle survives environmental test, storage, shipment, etc.
- Abbreviated Functional
 - System aliveness check run during environmental testing
 - Makes sure all subsystems can power on and communicate



Environmental Testing

- Various tests that subject spacecraft to simulated launch and space environments
 - Inspection/Functionals
 - Repeated after each environmental test
 - Pressure & Leak
 - Only for propulsion subsystems
 - Sine Sweep
 - Random Vibration
 - Thermal Cycling
 - Testing also helps validate thermal model
 - Thermal Vacuum
 - Most realistic environment of all earth-based testing
- Ensures spacecraft will not fail during launch or in orbital environment

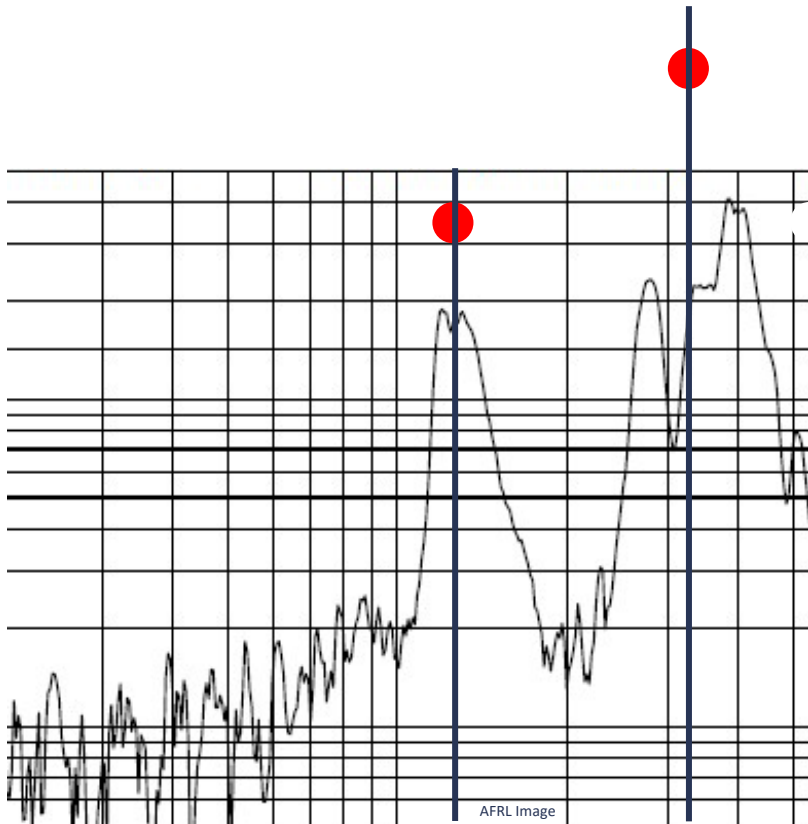
CubeSat Vibration Testing

- UNP vibration tests are typically conducted with the CubeSat inside a test dispenser
- Dispenser is rigidly fastened to a shaker table
- Satellite is shaken in all three axes; 1 minute of duration each.
 - In most circumstances, the order of axes doesn't matter
- The launch vehicle (LV) provides the required testing levels



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UNP What is the Measure of Success? Pre- and Post-test Response Comparisons

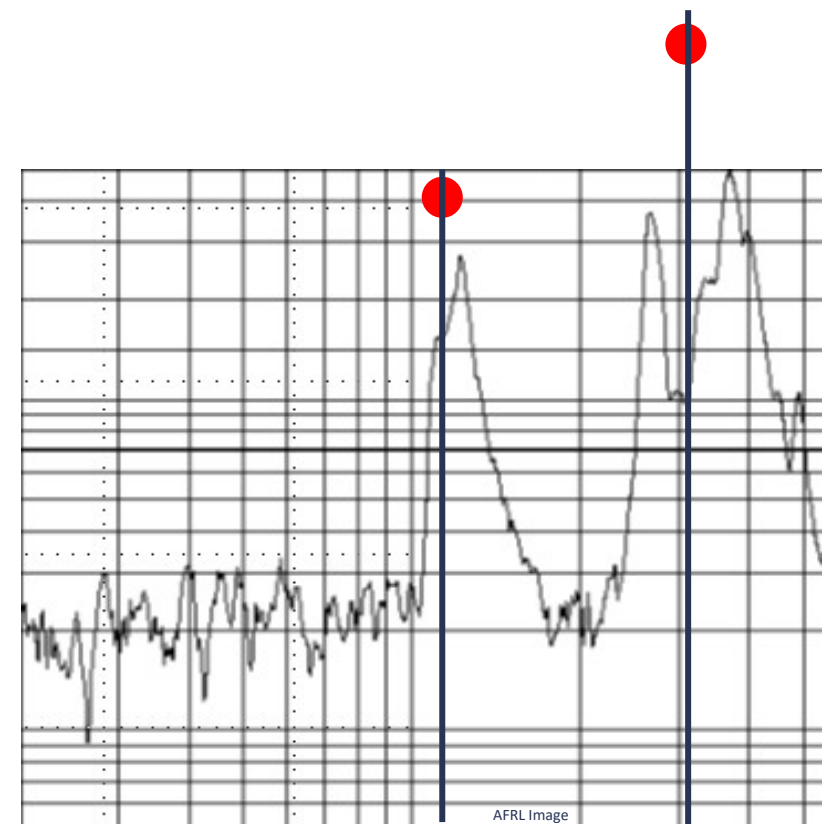


Sine Sweep pre-random vibe

Peaks appear to be clipped, red dots are likely the actual peaks

UNP criteria: Peaks should shift less than 10% in frequency and less than 20% in amplitude pre to post

Peaks appear to have minor changes in frequency and amplitude. Axis labels not shown here, but quantitative comparison required



Sine Sweep post-random vibe



Three types of thermal tests normally conducted on space flight hardware:

- Thermal Balance Test
 - Demonstrates the ability of the vehicle's thermal control subsystem to maintain specified temp limits for various operational scenarios. Also, provides data necessary to verify the analytical thermal model.
 - Can be combined with the thermal vacuum test.
- Thermal Cycle Test
 - Exposes hardware to specified hot and cold temperature extremes, and the transitions between them.
 - Detects design defects and demonstrates the vehicle's ability to withstand the stressing thermal environments.
 - Usually performed at a lower level of assembly, to qualify individual components. Can also be the fall-back test for vehicles in situations where desired thermal vacuum conditions cannot be achieved.
- Thermal Vacuum Test
 - Demonstrates the vehicle's performance under the combination of thermal vacuum conditions and temperature extremes.
 - Detects material, process, and workmanship defects that only respond to vacuum and thermal stress conditions. (Historically, more defects are discovered via T-Vac testing than from any other environment.)

