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

10 July 2023

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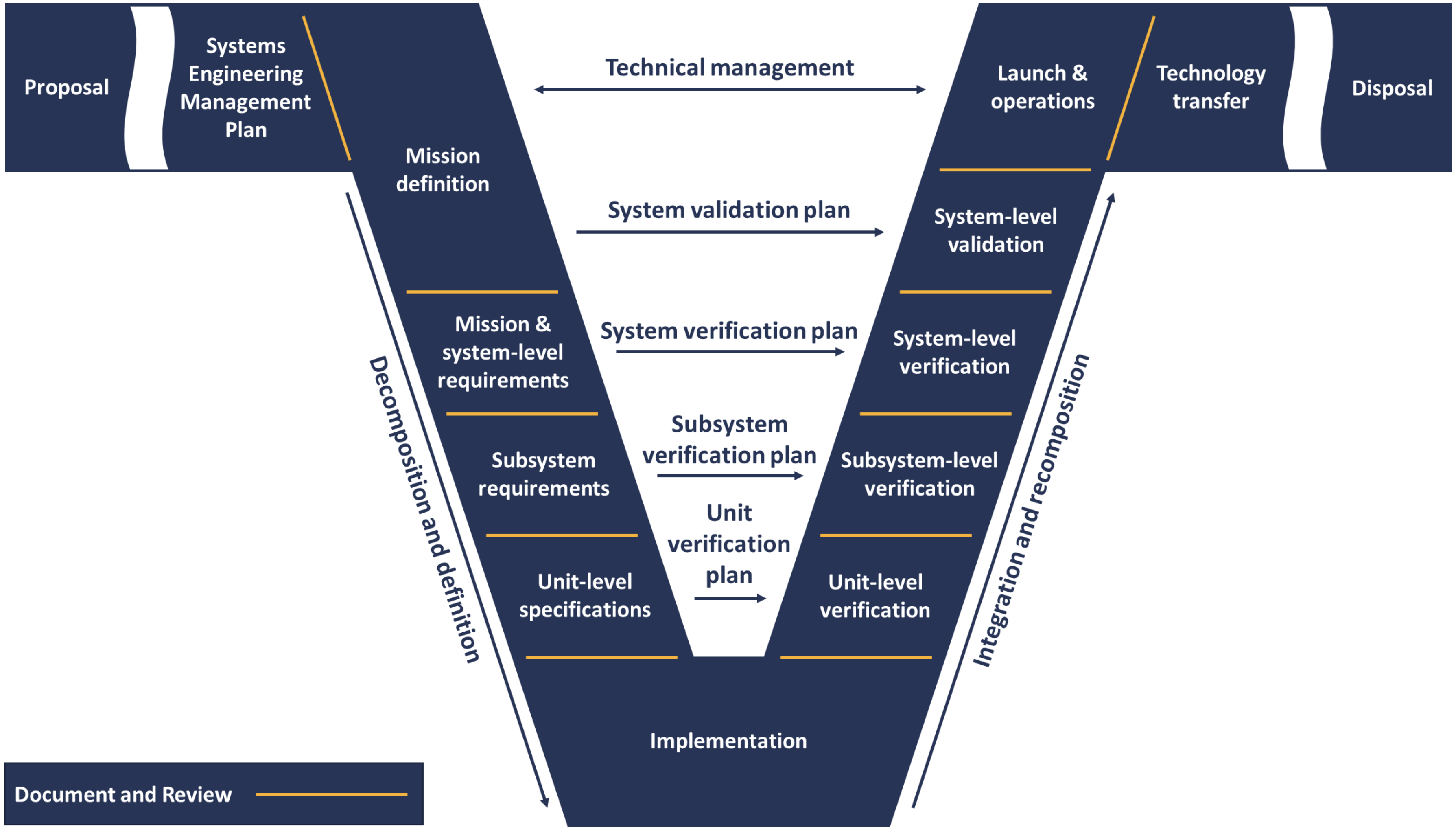
Exploration Research and Technology Programs

Assembly, Integration and Test

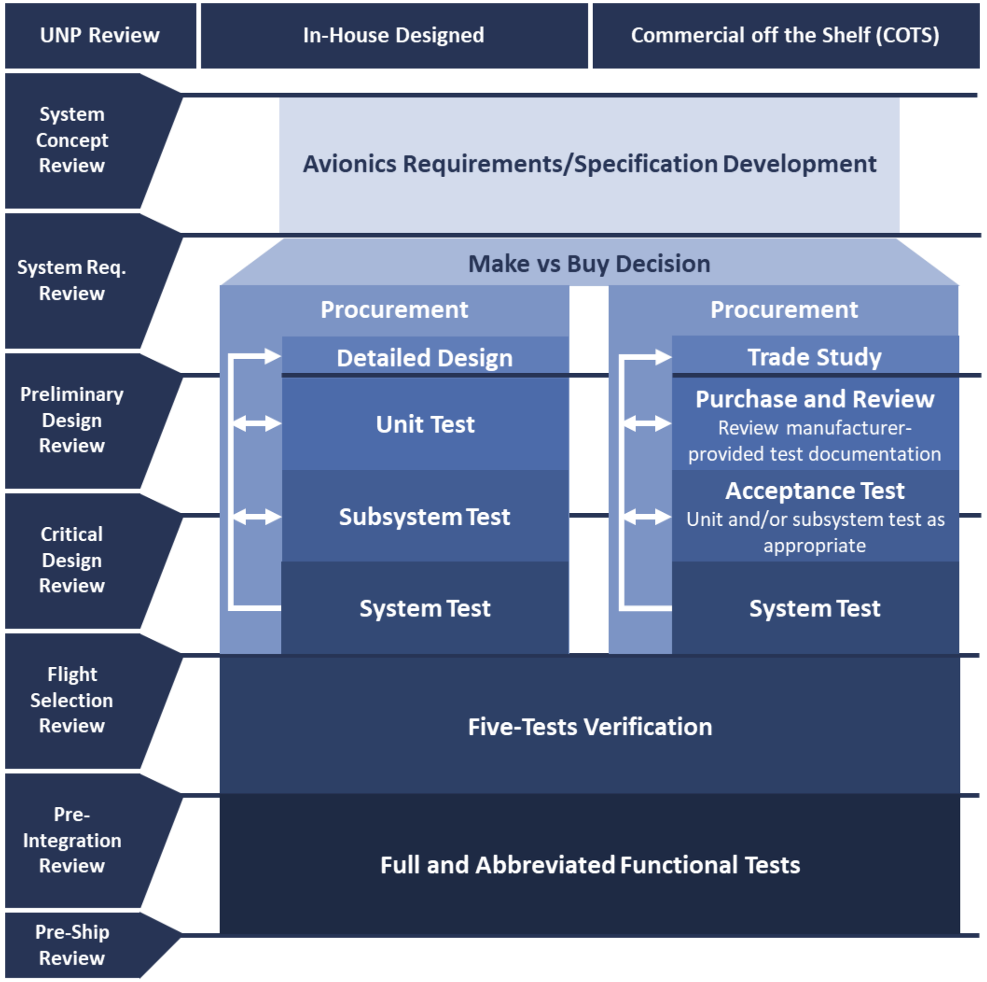
AI&T: The "V"



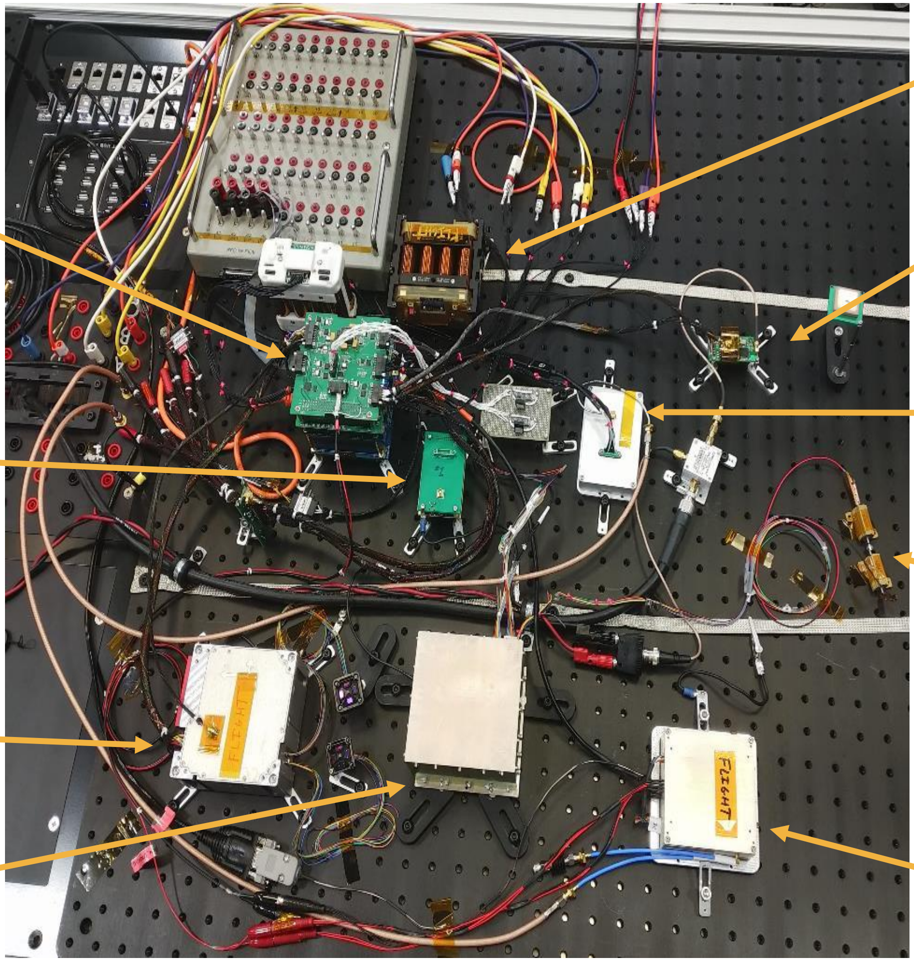
Proposal
Systems Engineering Management Plan
Mission definition
Technical management
Launch & operations
Technology transfer
Disposal
System validation plan
System-level validation
Mission & system-level requirements
System verification plan
System-level verification
Subsystem requirements
Subsystem verification plan
Subsystem-level verification
Unit-level specifications
Unit verification plan
Unit-level verification
Implementation
Decomposition and definition
Integration and recomposition
Document and Review

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?



Example: VPM



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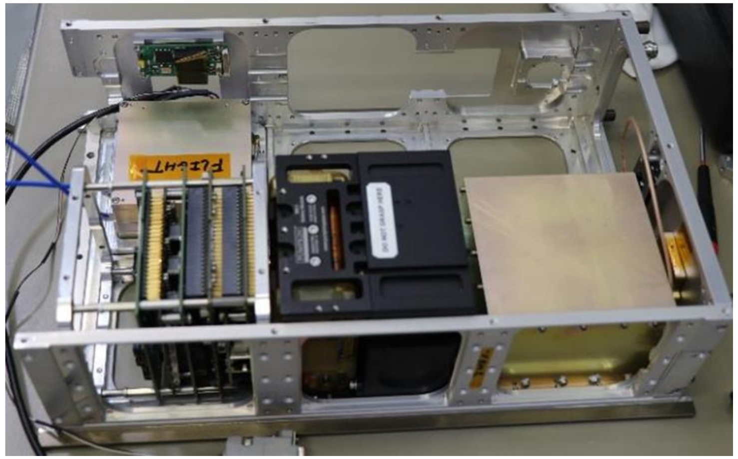

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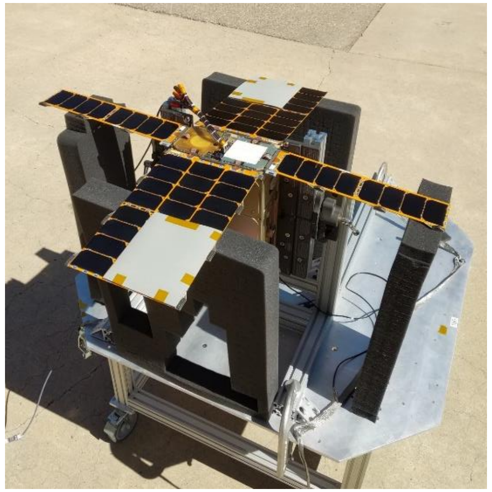

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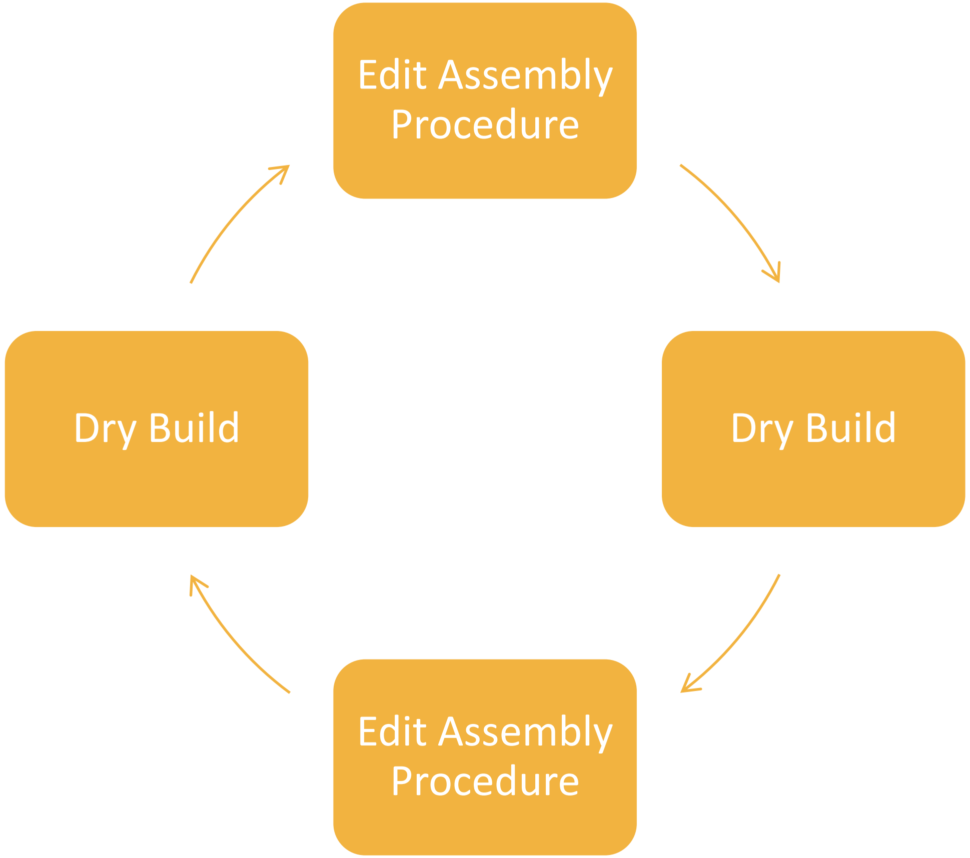
Assembly

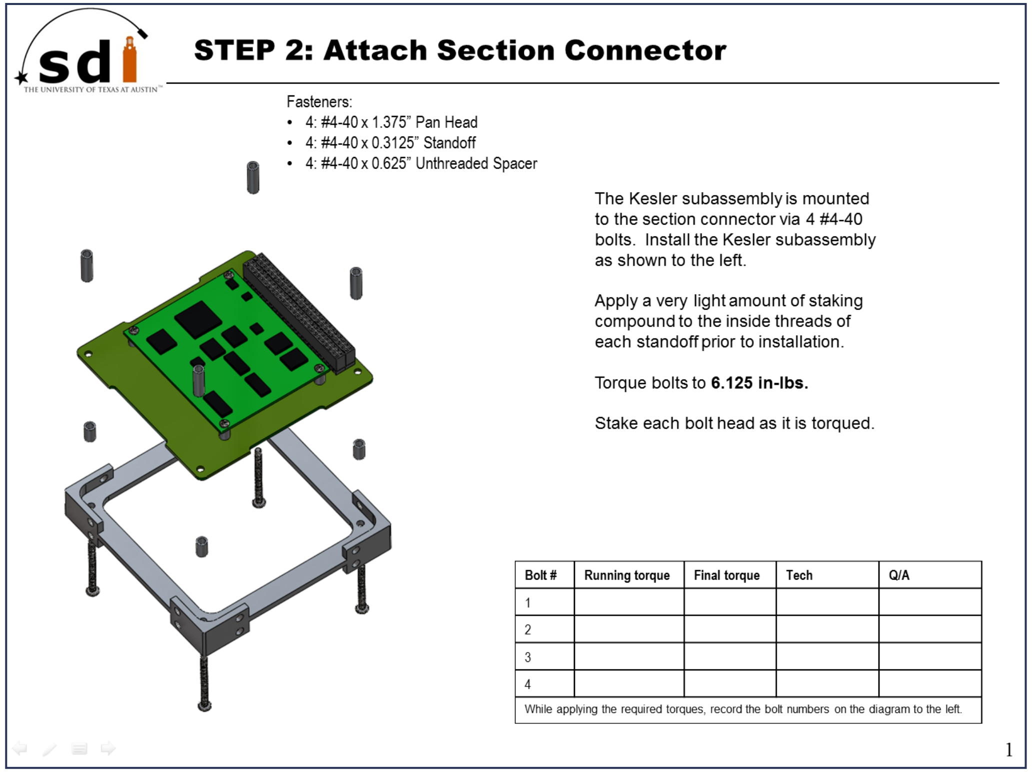
Assembly Tips and Tricks

- 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



Procedures

- 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



THE UNIVERSITY OF TEXAS AT AUSTIN

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				

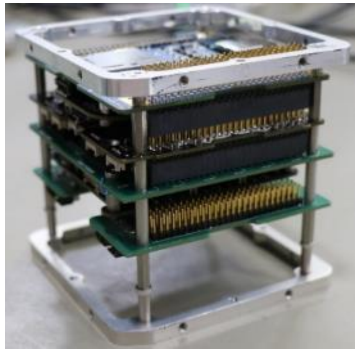
While applying the required torques, record the bolt numbers on the diagram to the left.

1

Image Courtesy of University of Texas at Austin

Dry Runs

- 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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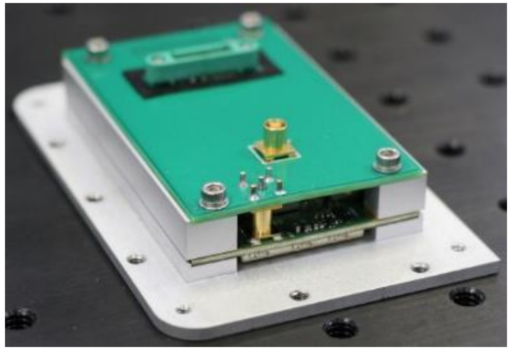

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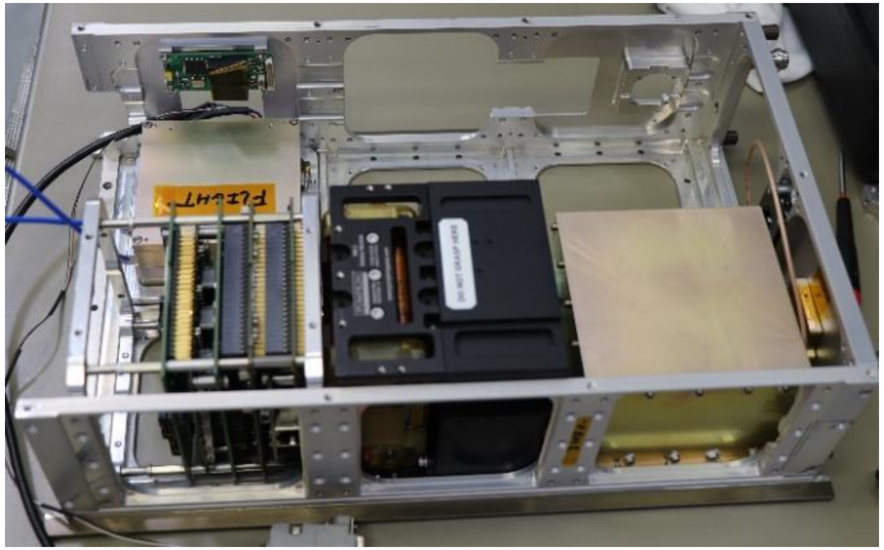

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Ground Support Equipment (GSE)

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

Integration Stand(s)

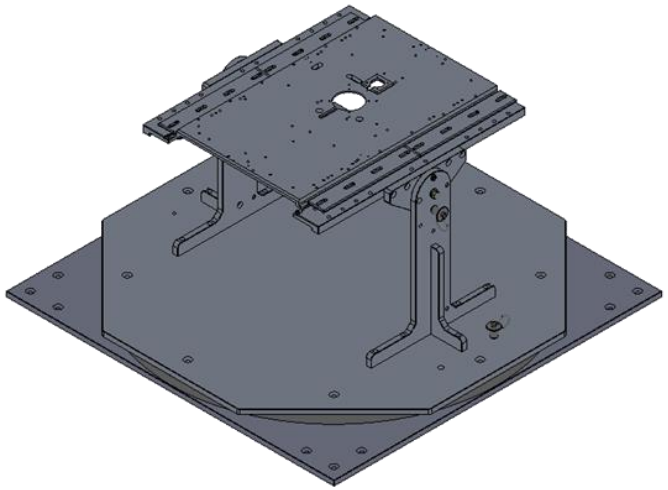
- Integration stands support the vehicle and subassemblies during integration
- When designing an integration stand, keep in mind
  - Access in multiple orientations
  - Secure restraint to prevent shifting or falling
  - Potential inhibit features
  - When the stand will be utilized
  - Electrical grounding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

Moving CubeSats

- 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



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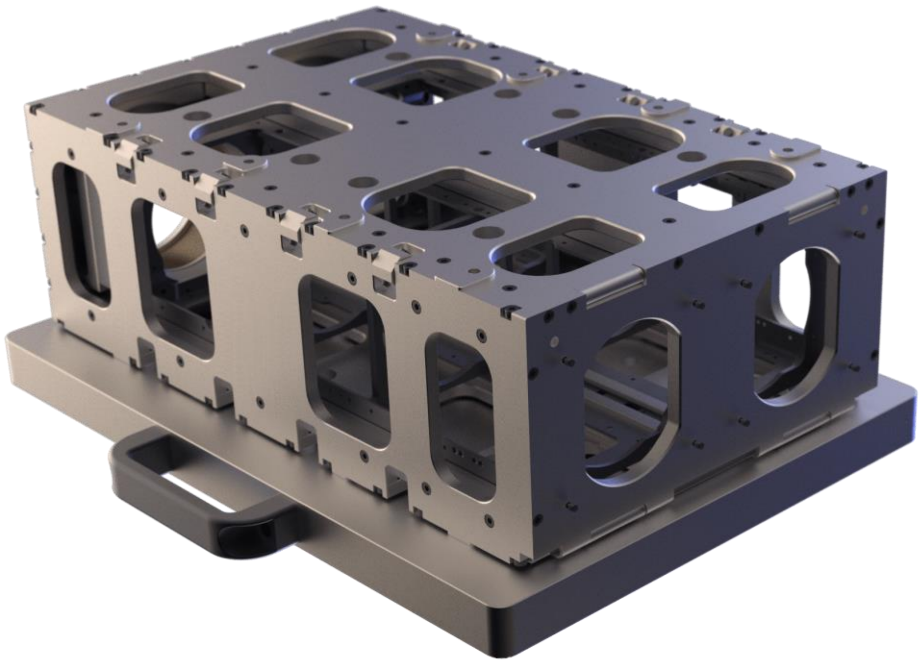
Integration and turnover fixture designed for CubeSats

Testing Interfaces

- 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

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

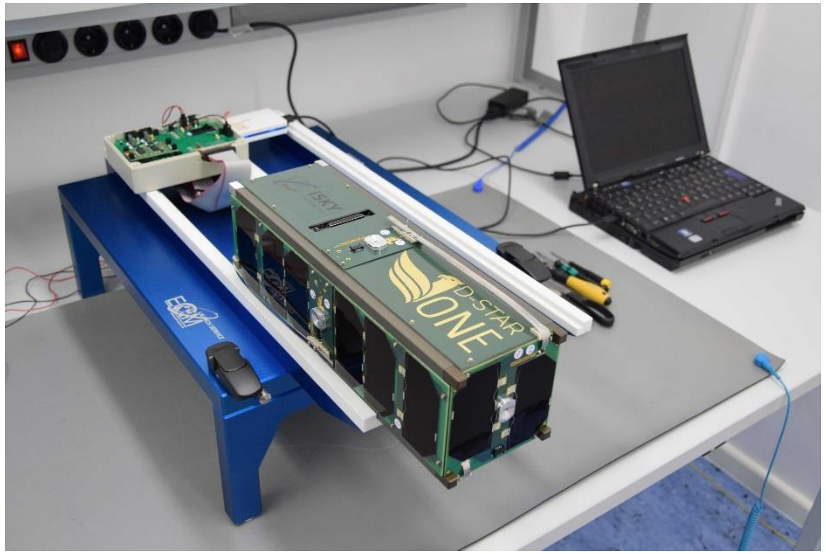
Electrical Ground Support Equipment

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

EGSE Connection



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

- 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

Charging Interface

mr-fahrenheit.com/communication/

- 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)

DO NOT leave batteries charging unattended

Flight Representative Communications Interface

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

- 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

Integration

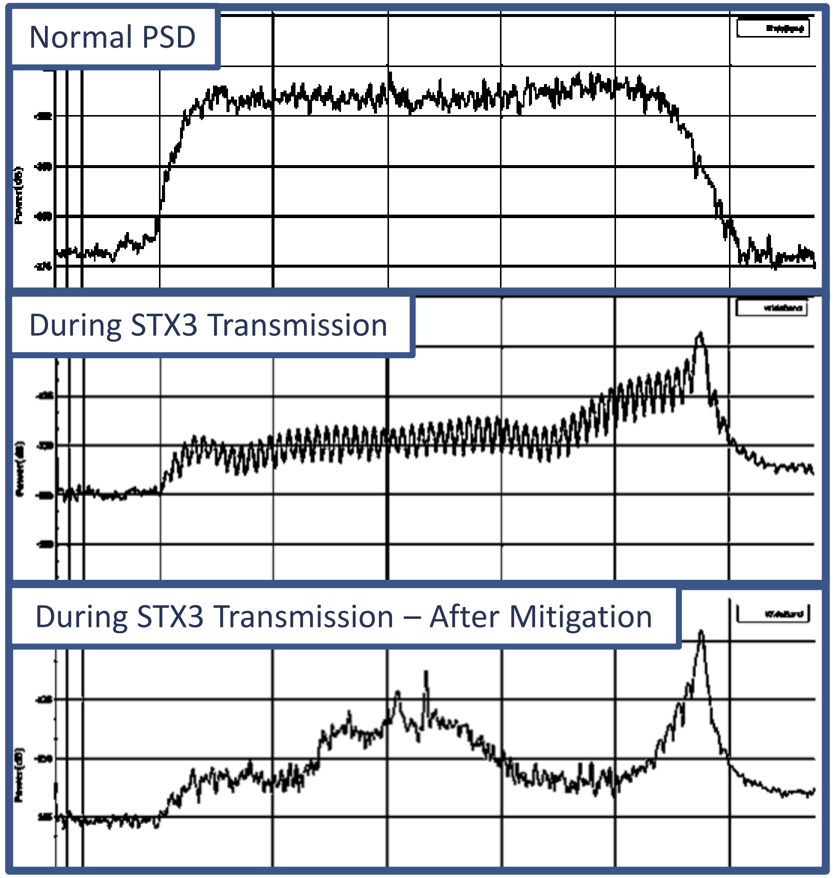
Integration

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

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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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

The Five Tests

- 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

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

What is Environmental Testing and its Purpose?

- 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

Expander Head (set for axial test)

Shaker

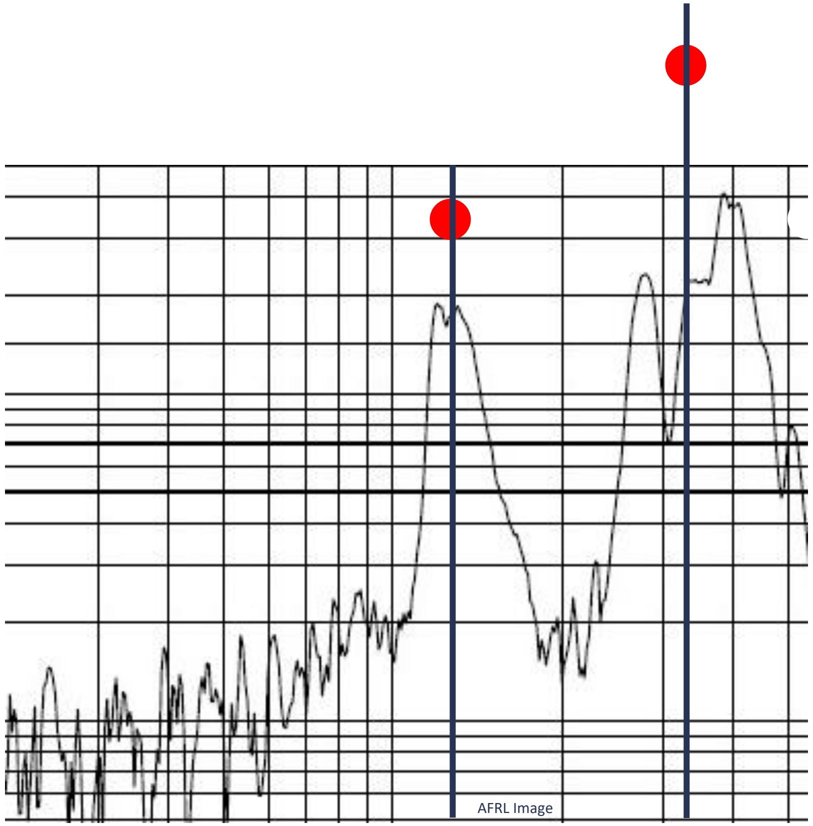
Slip Table (not used for axial test)

Expander Head (rotated 90 degrees for lateral axis testing)

Slip Table

AFRL Image

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

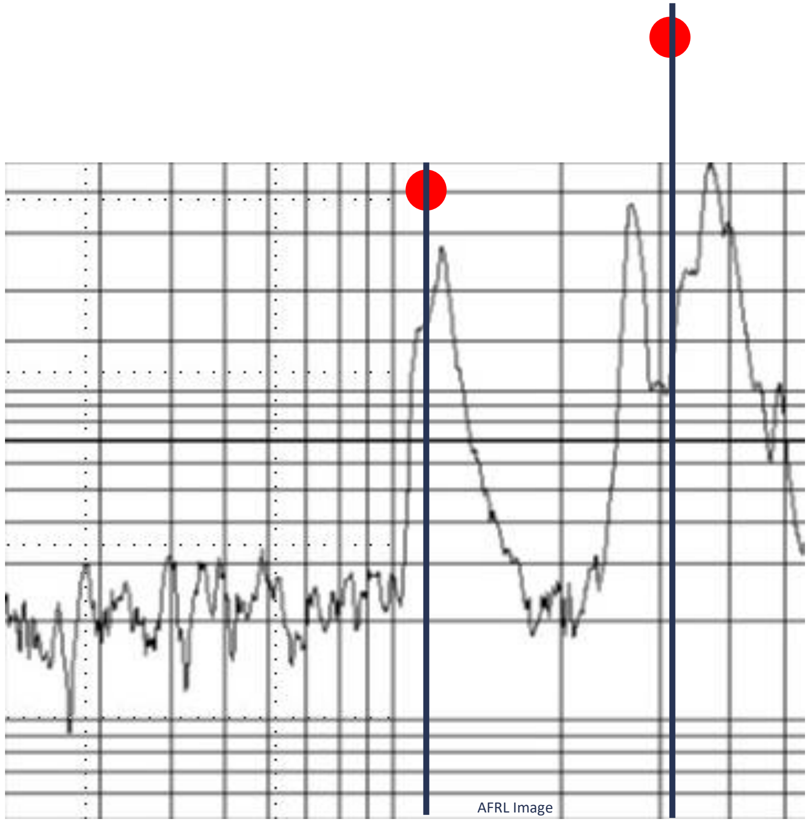


Sine Sweep pre-random vibe

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

Thermal Testing

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.)

Questions?