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Assembly, Integration and Test of Large Optical Systems

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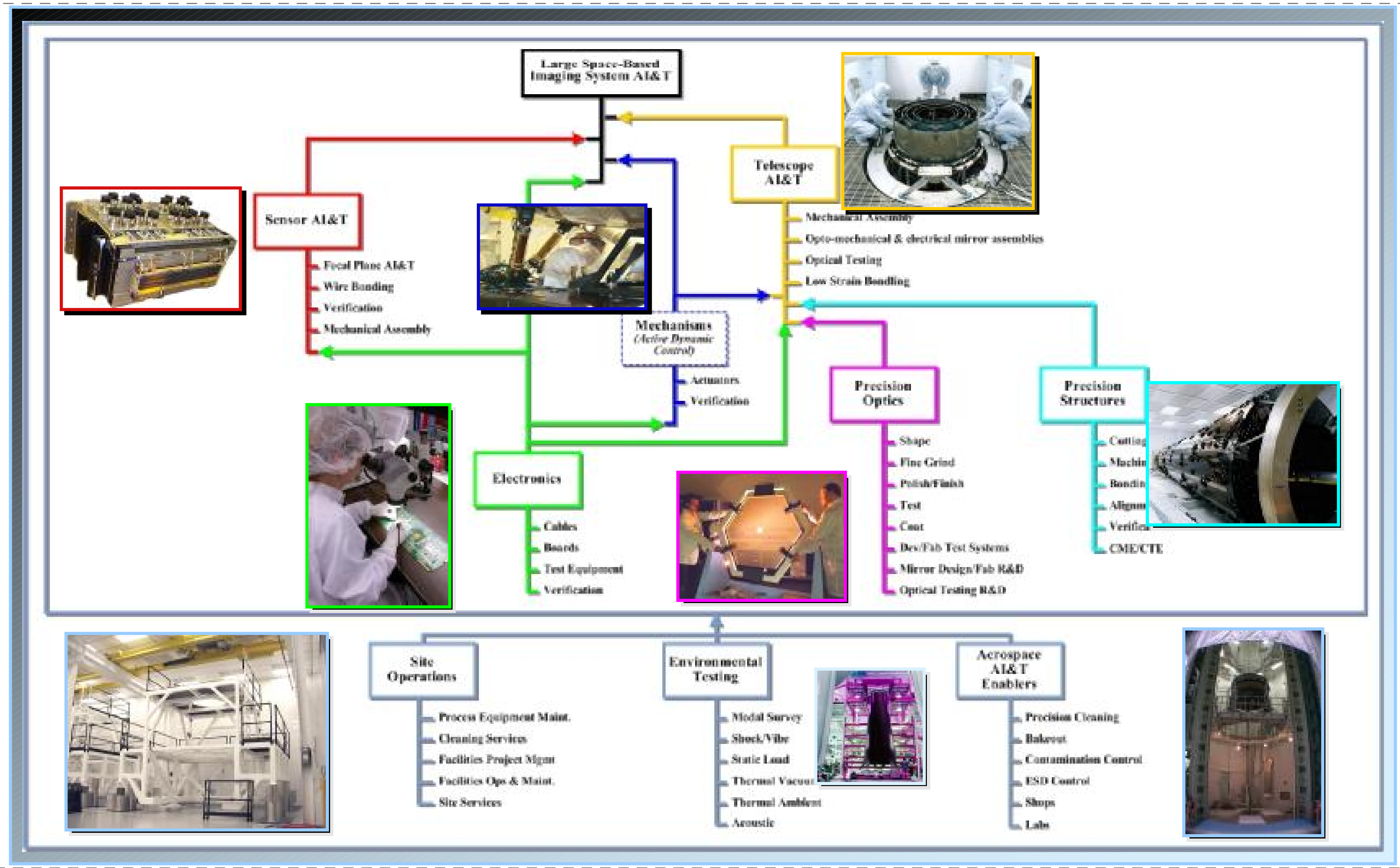
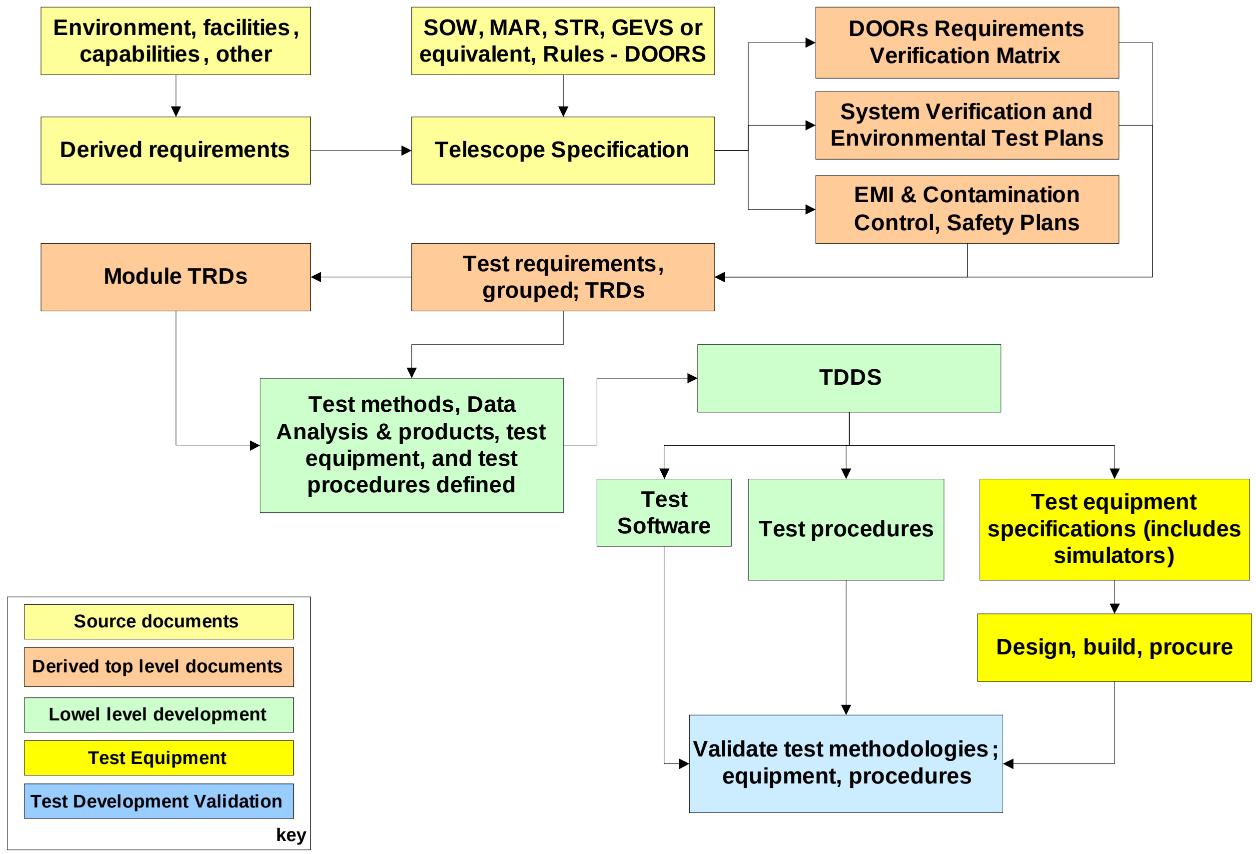
The Basics

- **Fundamentally, assembly, integration and test of a large optical (>1m aperture) system is no different than that of a smaller system (<1m)**
- **Top-level requirements must be identified and verification plan put in place and followed**
  - Plan must be consistent with technical (performance) and programmatic requirements (cost, schedule, risk)
  - Acceptable verification methods per the NASA Systems Engineering Handbook (SP-610S)
    - Test
    - Analysis
    - Demonstration
    - Inspection
    - Simulation
    - Validation of Records
- **<u>All</u> space systems rely on some combination of these methods for final ground verification**

Assembly, Integration and Test Flow



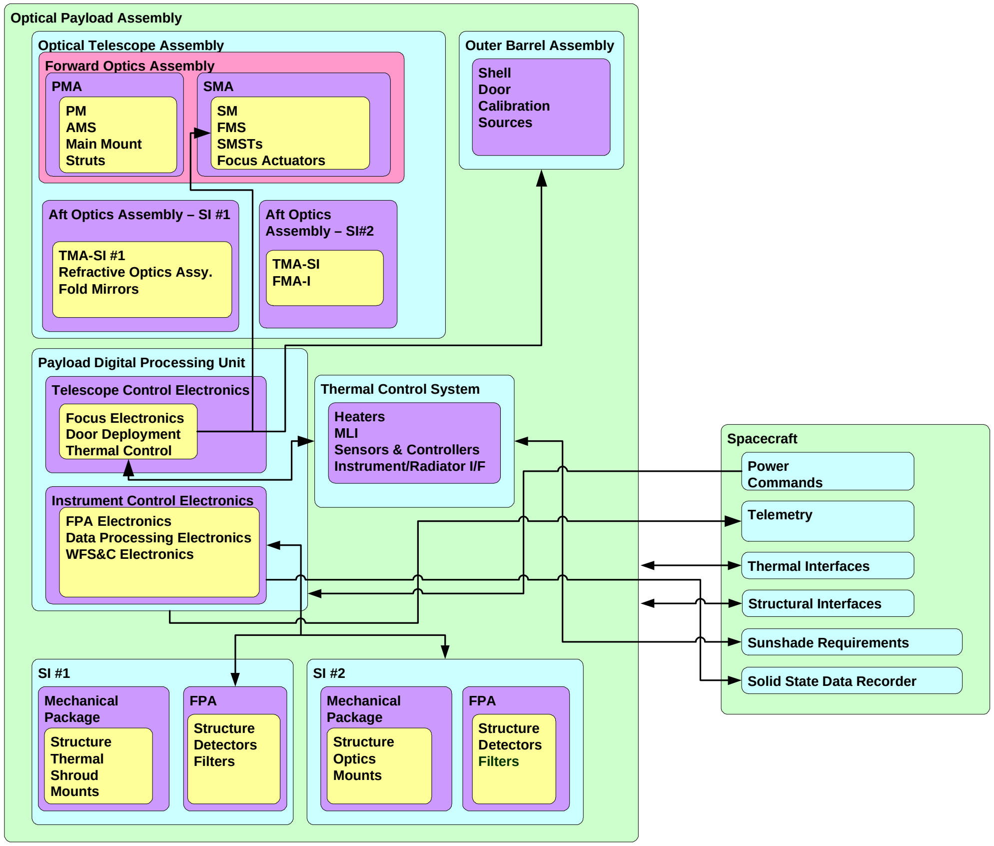
Requirements-Based Test Program Flow



Test equipment, processes and procedures
must be consistent with hardware/software performance requirements

Testing Hierarchy

- Verification testing starts at the component level
- Verification occur as at each subsequent level of assembly
- End-to-End functional testing of an optical payload is always desirable
  - Even better when testing of an entire observatory is performed
- However……..



Even at a high level, there are dozens of assemblies that must be verified

However…….

- **An end-to-end test does not guarantee mission success**
  - If done improperly, it adds no value and can give a false sense of security
  - If done properly it can be:
    - Expensive
    - Time consuming
    - More complicated than the mission itself
- **Remember, every space mission relies on some level of analysis for final verification; on earth it is impossible to:**
  - Perfectly simulate Zero-g
  - Perfectly simulate the thermal environment of space
  - Perfectly simulate the dynamic environment of a payload
  - Perfectly simulate space weather
  - Build a test set (of any kind) with no uncertainty

A Successful Example

- **Chandra is perhaps the best example of a successful "end-to-end type" test of a large system**
- **Chandra's end-to-end-test was:**
  - Relatively expensive
    - Required the upgrading of XRCF at Marshall at a cost in the $10's of Millions
  - Bought-off against requirements based on analytical predictions of performance in the XRCF environment
    - Gravity effects were modeled using FEA and optical analysis code
    - Thermal effects modeled using FEA and optical analysis codes
  - Did not fully verify the entire optical payload simultaneously
    - HRMA was tested and calibrated for 4 moths using engineering model Science Instrument
    - Testing done with HRMA and flight SI was an abbreviated 2 week test to demonstrate system was behaving within allowable parameters
  - A complete success as demonstrated by Chandra's contributions to astronomy
- **To mitigate test uncertainty risks, Chandra utilized two basic engineering principles**
  - Chandra verification plan was developed to ensure that system would perform within capture range of flight system adjustable parameters
    - Temperature set point of HRMA was adjustable
    - Focus of system could be adjusted
  - Performance error budgets had adequate margin

When things get more complicated….

- **Missions such as JWST and TPF-C are even more challenging than Chandra**
  - Are “end-to-end” tests still viable?
    - Yes, if clear pass-fail criteria can be established in conjunction with a test methodology that is compatible with flight requirements, cost, schedule and risk
- **Challenge in testing these systems is recognized**
  - TPF-C will be able to leverage lessons learned on Chandra and JWST
  - Excerpt from JWST Science Assessment Team Interim Report (26 July 2005)

“JWST is a space telescope of unprecedented aperture, but it is also cryogenic and passively cooled, a challenging combination. This means that ground-test verification that JWST will perform as planned on-orbit involves not only accommodation of the difference between 1-g and 0-g, but also a thermal environment that is very difficult to replicate. Demanding a full-up demonstration of JWST’s performance on-orbit could involve test equipment that rivals the sophistication and complexity of JWST itself, potentially adding substantially to the capital cost and the time line to become one of the major expenses in the mission. While such a demonstration is desirable in this or any project, it is unlikely that it will be affordable.

This raises the question, to what extent is a full-up, end-to-end, simulated performance on the ground necessary? The experience with the Hubble, where the primary mirror was figured to the errant radius-of-curvature, which resulted in serious spherical aberration, has naturally led to a cautious attitude about performance verification before launch. However, it is easy to take the wrong lesson from the HST experience.”