Large Optical Systems Integration, Test and Verification

Robert Egerman
ITT Space Systems Division

Fundamentally the process of integration and test of large optical space borne systems is no different than the process which needs to be used on any space system. Because we are unable to perfectly reproduce space conditions on the ground, we must rely on a combination of techniques to verify and "buy-off" any space payload before it can be launched. Testing is a significant part of the verification process and deserves critical attention. However, other verification techniques, which per the NASA Systems Engineering Handbook (SP-610S) include analysis, demonstration, inspection, simulation and records validation are all important methods to be considered. The main point here is that the early design work of any space system should not focus on how the system will be tested prior to flight, but rather how it will be **verified** prior to flight.

Given that large optical systems might be considered by some to be more complicated than many other types of systems (See Figure 1), a disciplined engineering approach must be applied to each subsystem in terms of design and verification. It is especially critical to give attention to the verification plan early on in the design process to reduce technical and programmatic risk. It is certainly preferable to have an end-to-end ground test to demonstrate optical performance of payloads on the ground. However, if the uncertainties in the test and in ground-to-orbit effects are not accommodated by design and/or operationally adjustable parameters (such as focus shift and temperature control), then such a test is meaningless. In other words, it is possible to demonstrate performance on the ground, and then not have the required performance on-orbit.

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, and
More complicated than the mission itself

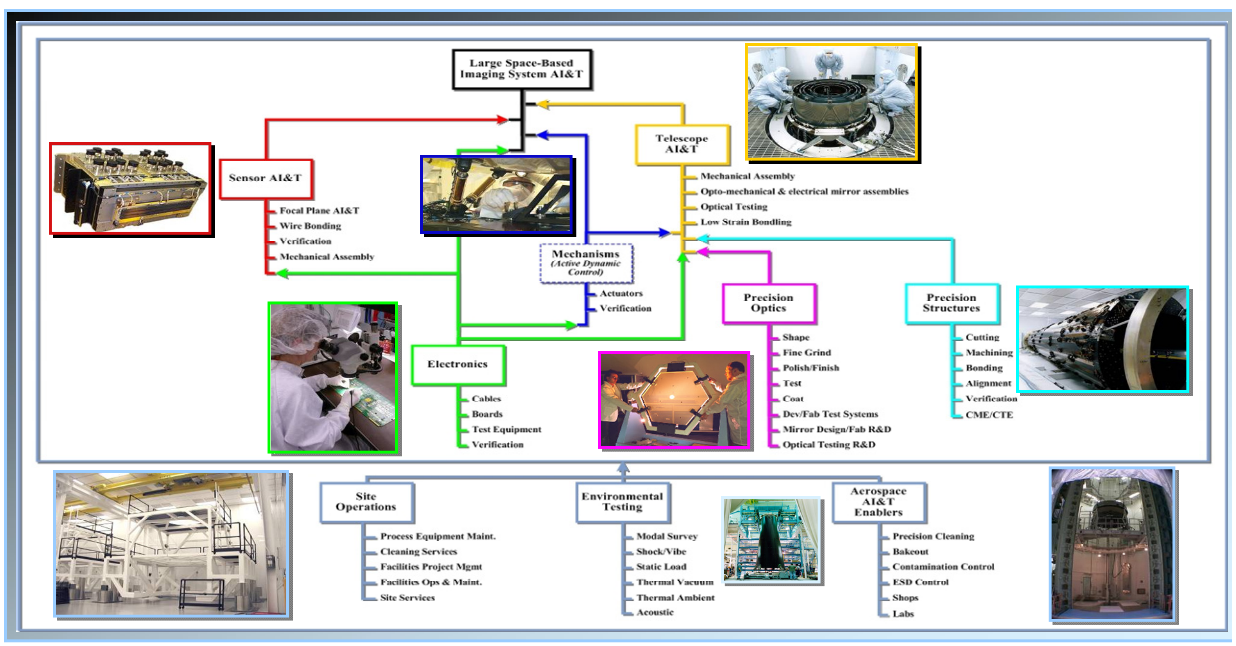

Figure 1: *Large Optical Systems Hardware and Verification Tree*

There have been many mission successes that have not included full up end-to-end testing of full observatories. The CHANDRA X-Ray observatory is a good example of this. Chandra underwent simplified end-to-end testing of the main telescope optics over a period of several months utilizing an engineering model of the science instruments. Final verification testing after the integration of the flight instruments was abbreviated lasting only a couple of weeks and optical performance was demonstrated to within 10% of the flight requirement. To mitigate test uncertainty risks, Chandra utilized two basic engineering principles:

1. The Chandra verification plan was developed to ensure that system would perform within capture range of flight system adjustable parameters (The temperature set point of HRMA was adjustable and system focus was adjustable)
2. Performance error budgets had adequate margin

The success of the verification plan implemented on the CHANDRA program has been demonstrated through the extraordinary imagery and science that has been generated from the observatory.

Future systems such as TPF and JWST face similar verification challenges that were addressed on CHANDRA. Though technically more challenging, the utilization of a disciplined systems engineering approach which focuses on system verification early in the design process can help ensure that these large programs are executed in an efficient, low risk manner.

The challenge in verifying large space borne systems is being recognized in the community. A good summary of this issue was documented in the 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."