Pre-Launch Risk Reduction Activities Conducted at KSC for the International Space Station

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Introduction

In the development of any large scale space-based multi-piece assembly effort, planning must include provisions for testing and verification; not only of the individual pieces but also of the pieces together. Without such testing on the ground, the risk to cost, schedule and technical performance increases substantially.

This paper will review the efforts undertaken by the International Space Station (ISS), including the International Partners, during the pre-launch phase, primarily at KSC, to reduce the risks associated with the on-orbit assembly and operation of the ISS.

Evolution of Philosophy

In any complex program, there is a natural pull or competition between designers and testing and verification (T&V) personnel. This is especially true concerning integrated testing (i.e. testing between end items.) Designers naturally think that a proper design that is adequately analyzed and properly built has little need for testing; basically, it will work as designed. T&V personnel understand the necessity to compensate for manufacturing and assembly errors that can creep in and the reality that sometimes things look good on paper but do not function that way. These competing philosophies can be complicated with lean budgets. The development of the ISS was no exception to this.

As the ISS moved through its design and redesign phases, as well as budget battles, the design centers espoused a ship and shoot philosophy. This philosophy stated that the Station elements would be tested at the factory, closed out, shipped to KSC, inspected for damage, integrated into the Space Shuttle then launched. There would be no integrated testing. Although primarily a design philosophy, cost and schedule also played a role.[1]

Meantime, ground operations personnel at Kennedy Space Center (KSC) understood from years of experience on Space Shuttle payloads, that items very seldom arrived ready to launch. In fact, as the payload community adapted to the Space Shuttle, the payloads became more complex requiring more and more T&V at KSC.[2] Although much testing was done at the factories, final integrated testing had to wait until closer to launch which meant at KSC.

As the discussions went back and forth between the ground operations personnel at KSC and the design centers, recognition of the need to do integrated testing gradually took hold. One issue that influenced the change was a 1991 Government Accounting Office study that criticized the fact that each of the four NASA design centers used their own standards in designing their elements.[3] This meant there was less of a chance of an element which performed well at the factory would perform well when hooked up to its "neighbor" on orbit. Finally, KSC personnel developed an alternate philosophy that stated that KSC would have the capability to test in the event ship and shoot didn't work.[4] As it turned out this capability was fully used as schedules and costs drove more testing at KSC.

As Station elements started moving from drawing board to reality, KSC championed testing that would demonstrate the elements actually connected properly and worked together. This idea was borrowed from The Boeing Company's experience with the 777. The 777 testing philosophy started out in the same manner as Station's – "quality" would be designed in. There would be little need for flight testing. The 777 went on to become one of the most heavily tested aircraft in history.[5] To help with the Station elements, KSC formed teams to visit and work in the manufacturing plants.[6] Ground Support Equipment was readied at KSC to perform testing as needed.

Finally, with delays on the Russian side of Station and another Program re-organization, fully integrated testing became a reality. This testing was called Multi-Element Integrated Testing or MEIT. MEIT was designed to test the physical, electrical and fluid connections for those elements under test. MEIT also differed from other testing in that it would be NASA run with contractor support. [7]

The International Partners were also able to take advantage of the MEIT process during their time at KSC. This was particular truly due to the schedule delays associated with the loss of the Space Shuttle Columbia. Taking advantage of this down time, the Partners were able to ship their elements to KSC to participate in MEIT that otherwise would not have been possible.

Testing Regimes for Sub-Elements

MEIT was designed for the testing of the major elements of the ISS. But what about sub-elements such as payload racks and payloads? These items depend on the ISS infrastructure to provide the necessary services much as a building does on the ground. To test these items, two primary pieces of Ground Support Equipment were developed –, the Payloads Test & Checkout System (PTCS) and the Partial Rack Check-out Unit (PRCU).

The PTCS included a large fixed unit, the United States International Standard Payload Rack (ISPR) Check-out Unit (USICU), located in the Space Station Processing Facility (SSPF).[8] The unit provided full scale testing of ISPRs with their associated payloads or facilities. The purpose was the same as the MEIT discussed above; that is, make sure things worked before going on orbit. Although some 7 individual racks were tested, the USICU was never used to full capacity; i.e. a full complement of MPLM racks at one time, before decommissioning.[9] The reason was that the traffic model it was based on never materialized due to budget constraints and the end of the Shuttle program.

The PRCU was the follow-on system. This smaller unit, of which there are several located at different sites, provides sufficient testing capability to ensure payloads meet their on-orbit performance characteristics. The PRCU is operated by NASA personnel who also gain hands-on experience in handling payloads. While many payloads are nearly ship and shoot, the additional time spent undergoing PRCU testing pays dividends in ensuring on-orbit safety and mission success.[10]

On-Orbit Anomaly Testing

As the ISS grew on orbit with the addition of different elements, failures and anomalies began to occur. While similar elements were at KSC, engineers were able to examine and run limited tests to validate design solutions. Additionally, flight crews, especially EVA personnel, were able to see similar hardware to that which was on orbit.

Also as word was received of on-orbit issues, testing for such issues were incorporated into ground testing, whether it was MEIT or stand-alone testing.

Issues Detected and Corrected During MEIT

As would be expected, numerous issues were identified as a result conducting MEIT.

- Perhaps the biggest area that benefited from MEIT was Command & Data Handling (C&DH). This being a heavily software-dependent function, it is perhaps not surprising. Two examples of issues that were discovered and resolved:

  During the initial power-up of Node-1, everything shut down. Had this happened on-orbit, months possibly would have been spent troubleshooting.[11] As it was, it only took a much shorter period of time to find and repair the problem.

  While testing the US Lab and in particular its interfaces with the Integrated Truss Structure, C&DH issues were discovered, that had they gone undetected, would have necessitated the return of the Lab from on-orbit, repairs conducted, then relaunched.[12]

- While mechanical, electrical and fluid issues were identified and corrected, none were as significant as the C&DH issues. Identification of these types of problems, enabled on-orbit assembly to proceed in a much smoother manner. For example, under MEIT, the rails for the Space Station Robotic Manipulator System Mobile Base Structure were tested for alignment and corrections were made. This process was much simpler on the ground.

Safety's Role in ISS Integrated Testing

Given that MEIT was a NASA run test, the role of Safety shifted from one of review of Contractor analysis to the role of actually conducting the analysis. For contractor operations, the contractor provided a safety data package prepared in accordance with ISS requirements. This package was reviewed and approved by the Ground Safety Review Panel (GSRP).

For MEIT, a new process was developed. As the elements themselves had already been through the GSRP, only the new interfaces and Ground Support Equipment (GSE) (such as connectors and hoses) unique to the testing needed to be analyzed. GSE that belonged to KSC was subject to its own review process.

To accomplish this analysis, NASA Safety adapted the Integrated Cargo Hazard Analysis process that was being used in the Space Shuttle Program. This process consisted of assessing the equipment against 10 generic hazards and determining that the hazards were properly controlled. This analysis was then reviewed and approved by NASA Safety Management. This process was able to leverage already existing work done through the GSRP and isolate only those items that were unique to the MEIT.

Additionally, NASA Safety Operations maintained oversight of the testing including reviewing of the hazardous procedures.

Summary

For almost any multi-component project, integrated testing is vital in discovering faults within the system prior to its deployment. Although it took several years of discussions, MEIT for ISS was finally accepted and immediately proved its worth. This worth was so great that MEIT became part of the normal routine of pre-launch testing at KSC, including the International Partner elements.

Safety's adaption of existing processes and data, allowed a relatively simple process to be developed that ensured that those new items brought by MEIT received the appropriate review.

Footnotes

1. Kenneth Lipartito and Orville R. Butler, *A History of the Kennedy Space Center* (NASA, 2007), page 348
2. Ibid. Page 349
3. Ibid. Page 353
4. Ibid. Page 354
5. Ibid. Page 360
6. Ibid. Page 362
7. Ibid. Page 364
8. Maynette Smith, interview, October 2011
9. John Dollberg, interview, October 2011
10. Maynette Smith, interview, October 2011
11. Ibid. Page 365
12. John Dollberg, interview, October 2011

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Introduction

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- This presentation will review the efforts undertaken by the International Space Station (ISS), including the International Partners, during the pre-launch phase, primarily at KSC, to reduce the risks associated with the on-orbit assembly and operation of the ISS.

Philosophy

- Natural competition between Design and Test and Verification (T&V)
  - Designers – Work as designed
  - T&V – Errors
  - Complicated by lean budgets
- Ship and Shoot
  - Test at factory
  - Closed out
  - Shipped to KSC
  - Inspection/Integration into Shuttle
  - Launch
- No integrated testing

Philosophy

- Ship and shoot had not worked for large payloads
  - Did work for mid-deck size payloads
  - Payloads became more complex to meet Shuttle capability
- Gradual change away for ship and shoot
  - 1991 General Accounting Office Study
    - Different sets of design standards
- Alternate philosophy proposed by KSC
  - Develop capability in case ship and shoot didn't work out
  - Specialized Ground Support Equipment (GSE)
    - Simulators/Emulators

Philosophy

- KSC push for Integrated Testing
  - Boeing 777
  - In plant KSC personnel
- Fully Integrated Testing
  - Multi-Element Integrated Testing (MEIT)
    - Physical, Mechanical, Fluid connections
  - NASA run vice contractor
- International Partners took advantage of MEIT Testing

Testing of Sub-Elements

- Testing GSE
  - Payloads Test & Checkout System (PTCS)
    - United States International Standard Payload Rack (ISPR) Check-out Unit (USICU)
      - Large fixed unit
      - Test multiple racks
      - Never fully utilized
  - Partial Rack Checkout Unit (PRCU)
    - Follow-on to PTCS
    - Drawer/Payload level
    - NASA operated

On-Orbit Anomalies

- Failures began to occur with assembly, as to be expected
- Other similar elements on the ground
  - Run limited tests to troubleshoot or validate fixes
  - EVA Crews get near hands-on

MEIT Issues

- Command & Data Handling
  - Software-dependent function
    - Initial Node-1 power up turned out to be power down
    - US Lab connections with the Integrated Truss Structure
      - If undetected, return and relaunch
- Mechanical/Electrical/Fluid
  - Typical discrepancies
  - Mobile Base Structure rails

Safety

- Change in role
  - NASA run vice contractor
  - For contractor operations, reviewed and approved by the Ground Safety Review Panel
  - Major units already approved
- New analysis developed
  - Used Shuttle developed process
  - Reviewed and approved by NASA Safety Management
  - Leveraged existing work
- NASA Safety Operations maintained oversight

Summary

- Integrated testing is vital
- MEIT so valuable, it became standard testing
- Safety adapted existing processes and data
  - Allowed simpler process
- Test as you fly, fly as you test